# TOOLS FOR THE SPATIAL ANALYSIS OF LAND AND FOR THE PLANNING OF INFRASTRUCTURES IN MULTIPLE-LANDUSE SITUATIONS

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Proefschrift
ter verkrijging van de graad van
doctor in de landbouw- en milieuwetenschappen
op gezag van de rector magnificus,
Dr. H.C. van der Plas,
in het openbaar te verdedigen
op vrijdag 12 juni 1992
des namiddags om vier uur in de aula
van de Landbouwuniversiteit te Wageningen

CIP-GEGEVENS KONINKLIJKE BIBLIOTHEEK, DEN HAAG

Jurgens, C.R.

Tools for the spatial analysis of land and for the
planning of infrastructures in multiple-landuse
situations / C.R. Jurgens. - Wageningen :
Landbouwuniversiteit Wageningen. - Ill., fig., tab,
Proefschrift Wageningen. - Met lit. opg. -
Met samenvatting in het Nederlands.
ISBN 90-5485-006-x
Trefw.: landinrichting / infrastructuren.

**ABSTRACT**

For the near future, at least for many western countries, land in use for farming will decrease. Among others, more land is needed for 'nature'. More attention is needed for the curtailing of excessive use of land for agricultural purposes in favor of more alertness to matters of ecology and for minimizing the waste of resources.

The study has put emphasis on two fields of research. On that concerning the spatial relationships of landuse, and on that concerning methods and techniques for making landuse plans.

Landuse planning is seen as a process in which physical planning, land development and land management takes place and involves the physical, biological and social organization of land. Land, the object of landuse planning, is seen as an interrelated set of non-biotic, biotic and anthropogenic complexes. Human possibilities for steering the processes within these complexes are limited. Chances for steering, however, lie within the use of the concept that the interrelated complexes have cybernetic qualities.

Three groups of computer programs have been developed for the support of landuse planners. The programs have been named: AKCI, INTRANET and ECONET.

AKCI deals with *automated cartography* of C.I.-data on land development areas. The data-files, called Cultuurtechnische Inventarisatie (C.I.), contain specific landuse data on such areas, and are data-files in use by the Government Service of Land and Water Use in the Netherlands. By interactive thematic mapping of the data, an in-depth visual investigation of the land development areas is possible.

INTRANET, the second group of computer programs developed, aims at aiding landuse planners dealing with (road)infrastructure related questions like how to optimize for travel and how for the allocation of landuse.

ECONET, the third group of computer programs developed in the study, deals with calculations concerning the network which is relevant for the natural dispersion of plants and animals. This group of programs allows, for example, the determination of meta-population habitat-areas and the corridor-system most relevant for the (re)colonization of niches.

The computer programs are to be used interactively, thus allowing impact analysis of possible changes in location and/or intensity of landuse. They can be used in the landuse planning quest of the answer to "what to do where".

## PREFACE AND ACKNOWLEDGEMENTS

For some time now, 'land' has been the object of my attention. Its spatial dimensions, with physical, biological and social magnitudes (socio-economic and institutional), invite analysis and have created in me an urge to make contributions towards better landuse.
This study is an attempt to contribute towards a better and wiser use of land by tackling some problems related to the planning of landuse.

Landuse planning is planning for the best use of land. It is addressing the questions of what to do, where to do it, and how it should be done. These are the elusive questions which landuse planners address as they employ their tools. I too do not have all the answers, nor the tools, but I am happy to contribute with this account of a methodology aimed at increasing the contents of the toolkit of landuse planners.

Special attention has been given to spatially relevant landuse planning data, concerning:

- agricultural use of land and its scatteredness;
- road infrastructure and related (non-)accessibility of land;
- ecological infrastructure.

A theoretical holistic outline is presented as a framework for planning, with emphasis on feedback procedures. It serves to legitimize the interactive computer programs constructed in the study.

This study was done at the Agricultural University of Wageningen, to which, after having once been a student there, I returned as a staff member in 1981. The outline for this study was formulated in 1985.
I was lucky to have had access to the services of a number of successive computers, starting out with a DEC-computer, and since 1986 to those of VAXes. Without these large computers, this study would never have reached its present state.
The same accounts for my two magnificent but comparatively small Sinclair-QL's and lately a Tulip-SX. They have seen many source-prototypes and several drafts of this text.

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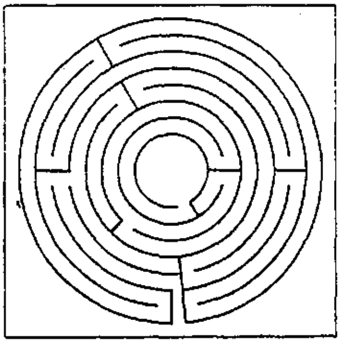

STELLINGEN

1. Landgebruik moet opgevat worden als een totaalproces van meerdere, van elkaar afhankelijke en elkaar beïnvloedende, veelal ruimtelijk verspreid liggende vormen van grondgebruik.
(dit proefschrift)

2. Het structureren van de abiotische omstandigheden, het aanpassen van de ruimtelijke maatvoering van gebruikseenheden en het dagelijks gebruik van grond beïnvloeden de politieke-, sociale-, demografische- en culturele dimensies van de samenleving.
Dergelijk activiteiten vragen een breed maatschappelijk draagvlak èn een evenwichtige afstemming tussen rechten en plichten van betrokkenen.
(dit proefschrift)

3. Voor een correcte belangenbehartiging dient ook het landgebruik buiten de ruimtelijk eenheid waar landinrichting plaatsvindt, actief betrokken te worden. Dit dient tot uiting te komen in de landinrichtingsprocedure; bij de voorbereiding van plannen, bij de analyse van de effecten van voorgestelde maatregelen èn in de besluitvorming.
(dit proefschrift)

4. Gezien de toename in intensiteit van antropogeen landgebruik dient de planning van landgebruik zich, méér dan voorheen, te richten op een systeemanalytische benadering van de gebruiksvormen.
De zogenaamde Cultuurtechnische Inventarisatie-bestanden lenen zich voor de vastlegging van data voortkomend uit dergelijk onderzoek en zullen dan voor planningsdoeleinden in belangrijkheid toenemen.
(dit proefschrift)

5. De beoogde landbouwkundige winst als gevolg van het slechten van wegen, weegt niet op tegen het verlies aan recreatieve- en natuurwetenschappelijke waarden.
(dit proefschrift)

6. Bij planning in landinrichtingsverband dienen wegenstelsels bezien te worden op hun verbindings- en ontsluitingsmerites voor verschillende vormen van gebruik. Daarbij dient eveneens overwogen te worden de verschillende grondgebruiken naar gunstiger ligging te verplaatsen.
(dit proefschrift)

7. Voor de planning van meervoudig grondgebruik is het noodzakelijk dat Geografische Informatie Systemen worden uitgebreid met beslissing-ondersteunende modules. De rol van optimaliseringsmodellen en -technieken dient in deze richting krachtig te worden uitgebreid.
(dit proefschrift)

8. Naarmate de rekensnelheid van computers toeneemt, is het onderzoek naar exacte oplossingsmethoden van complexe vraagstukken, relevanter dan soortgelijk onderzoek naar heuristische methoden.
(dit proefschrift)

9. Ter vermijding van begripsverwarring dient het in de landinrichting gebruikte woord **evaluatie**, doelend op het inschatten van op te treden effecten als gevolg van voorgestelde landinrichtingsmaatregelen, vervangen te worden, bijvoorbeeld door het woord **effectverwachting**.
(dit proefschrift)

10. De bestuurderen van de Landbouwuniversiteit dienen serieus te overwegen de huidige naam van de universiteit te verkorten tot Universiteit Wageningen, danwel daaraan een persoonsnaam te verbinden.

11. Er dient ten spoedigste een aan televisie en radio toe te voegen module te worden ontwikkeld, die de ontvangst van reclame-uitzendingen, naar wens van de kijker/luisteraar, kan blokkeren.

12. Het oefenen van geduld in het kader van de bestrijding van milieuvervuiling, is geen schone zaak.

13. Het is te verwachten dat in de voormalige Oostblok-landen de roep om te komen tot een geleide economie, vooralsnog zal toenemen.

**C.R. Jurgens**
**Tools for the spatial analysis of land and for the planning of infrastructures in multiple-landuse situations.**
Wageningen, 12 juni 1992

I wish to thank all who have contributed to this research, not the least of whom are the students of the Department of Land and Water use. Some of them have spent many hours programming, having at the same time become talented programmers.
My thanks are directed towards Theo Thewessen for his pioneer work on AKCI, the work later continued by Reinoud Dorresteijn and Willem Kuijpers. Special gratitude is certainly due to Bert Huijskes and Wim van Lemmen with whom many hours have been spent creating the foundations of INTRANET. Their work has been fruitfully continued by Max van Staveren and Jan-Willem Lapoutre.
My thanks also go out to the student group consisting of Marcel Busser, Cecile van Deijck and Marcel Jansen for the suggestions concerning the use of INTRANET for the planning of touristic infrastructures. Similar thanks go to Willem Faber for using and testing INTRANET as an impact-analysis planning module for the purpose of planning recreation and that of the protection of nature.
I again wish to mention Max van Staveren, this time for his contributions towards ECONET. Thanks also are due to Frank van den Berg and Dick van Dorp for their remarks on the ECONET features and for their research data on the study area called Binnenveld. This has allowed me to zoom in on specific needs concerning the ecological impact analysis of land-development areas.
I am indebted to Wim van der Knaap with whom many computer related questions have been discussed and tackled.

My gratitude also goes to my two promotors, Prof. Hubert van Lier and Prof. Paul van Beek. Their remarks and guidance can be found in this study. I hope this study contributes towards a stronger liaison between their two areas of science, that of Landuse Planning and Operations Research respectively.
A word of thanks is due to Prof. Pat Taylor of Texas University (USA), who has guided me in the use of English.

Last but not least, I wish to express gratefulness to my wife and children. I am grateful for their acceptance of my many off-duty hours of work, knowing that what not has been given them, cannot really be compensated in time to come.

## SUMMARY

Landuse planning is the activity consisting of physical planning, land-development and land-management, involving individual and collective thinking, directed at the physical and social organization of land. Land, the object of landuse planning, is interpreted as an interrelated set of non-biotic, biotic and anthropogenic complexes. The ultimate goal of landuse planning is sustainable development of land. For reaching such, in landuse planning there is the need to use techniques and methods basically directed at the optimization of a multitude of goals.

Human possibilities for steering the processes within these fields of interest are limited, but lie within the understanding that these processes have cybernetic properties. The complexity of the interrelationships creates shortages in knowledge concerning the day to day processes and the conditions under which these occur. This complexity causes uncertainties about the effect of landuse proposals. It also causes a need for a better understanding of causes and effects. A combined effort of monitoring and modelling with sensitivity analysis and feedback creates possibilities for estimating the effects of human action.
This combined effort, when followed, can ensure finding landuse plan-proposals worthy of implementation.

The study has concentrated on spatially relevant data and on developing related tools for landuse planners. It has resulted in sets of computer programs called AKCI, INTRANET and ECONET.

AKCI stands for *automated cartography of C.I.*, with C.I. standing for data-files called "Cultuurtechnische Inventarisatie". These data-files with data on land development areas are used in landuse planning by the Dutch Government Service for Land and Water Use.
The data-files are (presently) strictly used for recording socio-economic data of agriculture holdings to which are added topographic data on landuse units. The use of these data-files has been upgraded by the computer program AKCI. This program allows visual and interactive investigation of the areas described by the data-files, by means of interactive display of thematic maps and basic data of land-units and holdings.

INTRANET is a set of computer programs for *interactive route analysis in networks.* With networks reference is made to labyrinths, for example road infrastructure complexes. Route-analysis is basic to many physical planning and land-management questions, whether for purposes of optimizing routing or accessibility for various landuses or for the management (for example for questions of layout and of road-quality) of the system itself. The calculation of accessibility and routing is based upon impedance values and length of links within the network.

The (rural) road system can be modelled as a network with nodes and links, with the nodes representing places of interest and positions of transition within the network, and the roads as links of the network.

Calculations concerning the distances between nodes and the routing between them is a computational burden when networks become large. With INTRANET, procedures have been found to reduce the mathematical burden, making it possible to use the program as an interactive tool for route analysis in land-development projects. It allows the calculation of distances, the determination of shortest routes, both simple and complex, and some labor-planning optimization.

With INTRANET fast calculations can be done for routing, for access to and from, and for time involved. By using the program interactively, contributions in landuse planning can be made towards impact analysis and towards finding the better plans.

ECONET is a set of computer programs primarily directed at enhancing the use of ecological data within landuse planning, specifically those concerning *ecological networks.*

Because nature is under pressure and areas with natural conditions are rapidly diminishing, it is necessary to increase ecological knowledge within landuse planning procedures.

With ECONET, the ecological interpretation of the location of habitat-areas and their spatial relationship, is based on the parameter distance. With ECONET, dispersion routes of species can be modelled by means of tracing the location of the minimum spanning tree of connections between habitat-areas within non-habitat areas.

In cases where the dispersion process is known to exist only within a specific corridor system, this network has to be pre-defined in order to limit the model-flow within that area only (ECONET2).

Taking size and form of ecological objects into consideration, together with those of objects obstructing the dispersion process, the modelling of the dispersion process becomes more complicated because bypasses have to be found (ECONET3).
With the ECONET programs, the location of the ecological infrastructure and the most easily isolated habitat areas can be determined and displayed.
Where (approximations of) dispersion rates of species are known, the clusters of habitat-areas forming the meta-populations can be calculated.
ECONET can be used interactively, thus allowing planners to deal with what-if questions. It upgrades the insight into the ecological values of land within development projects. These programs too contribute to the finding of the better plans.

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Note: Figures of AKCI, INTRANET and ECONET which are not presented in colour, have undergone minor modifications for purposes of a better black and white presentation.



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# 1. INTRODUCTION

The presented study is based upon the expectation that in the near future, at least for many western countries, land in use for farming will decrease. More land is needed for 'nature', for landscaping and for recreational purposes. This expectation is mainly based upon a continuing situation of surplus production, while on the other hand environmental restrictions are in order to safeguard a possible sustainable development[1] for subsequent generations.
More attention is needed for the curtailing of excessive use of land for agricultural purposes in favor of minimizing waste of resources.
More alertness to matters of ecology is appropriate. For the latter there is a need for a better understanding of the major landuses in their spatial context and in mutual relationship.

In this study emphasis has been put on two major fields of research as a strategy for answering the above indicated challenge. These fields are those of:

- research directed at a better understanding of geographic/topographic landuse units and processes occurring within the environment, and
- research directed at creating methods and techniques for making landuse plans and guiding decisions to be made.

The research has focussed upon the question what new tools for spatial analysis and planning of infrastructures should be developed, and secondly by focussing upon the actual development of such tools.

It has resulted in a study centered on:

1 On instigation of the Secretary-General of the United Nations a commission was established in 1983 to make a proposition for long-term environmental strategies for achieving sustainable development by the year 2000 and beyond. The World Commission on Environment and Development, headed by G.H. Brundlandt wrote 'Our common future' (1987) and gave the following definition of sustainable development: "paths of social, economic and political progress without compromising the ability of future generations to meet their own needs."

-- concepts of land, landuse and landuse planning as a framework for design and design related research (chapter 2);

-- methods using data for solving the "what and where" questions with emphasis on the spatial context of landuse units, infrastructure system and landuse (chapter 3 ,4 and 5);

Especially in densely populated areas with heavy demands for the use of land for a variety of landuses, knowledge of the existing landuses in their spatial context is needed.
Land conditions and landuses interrelate and from a landuse planning point of view, the social, economic and environmental parameters are to be known and understood in order to establish paths for reaching sustainable development of such areas.
Where cultural patterns are such that land in landownership[2] gets scattered, for example by rules of heritage or by selling and buying activities, the relocation of landuse in conjunction with adjustments of the parcellation (size, shape), 'farm'size[3] and access of land is important. This type of problem, manifest in the country where the study presented here took place, in fact is present within many countries all over the world. Countries with no more 'virgin' areas to be developed and heavily depending on areas already in use, are presently (or will be in the near future) facing the question how to readjust to modern requirements. Action due, will certainly have to be based also on the knowledge of the effects of the layout and condition of its (road)infrastructure system on related landuse and the traffic generated by it.

-- methods for the design of the (road)infrastructures for solving questions related to the (non-)accessibility of landuse units, to the optimum

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2

Basically *ownership* is not that important, as it is the land*use* that is the determinant.

3

Reference is made to the organizational unit which decides how land-units are going to be used. The organizational unit does not have to be agriculture oriented.

location of planned activities and to the quality of the infrastructure itself (see chapter 4);

Accessibility of land is an important factor determining whether optimal use is made of the land. Size, form and location of land in relationship to that of other landuse units is of importance for the determination of the value and quality of the land.
From the point of view of sustainable development, a reduction in travel demand, in energy spending and in spill of land and that of time, is called for.
The implicit hypothesis was formed that planning for road-network layout, road-construction and optimal travel routing, must lead to plans in line with sustainable use of land.

-- methods for the support of the decision making process in which answers have to be generated such as: Where to locate the different landuses in view of ecological processes? (see chapter 5);

Sustainable development not only refers to the needs of future generations, but to having to abide by levels of use of land acceptable from an ecological point of view. Especially in areas heavily used by man, the ecological functioning of land is heavily under pressure and endangers the sustainable use of land.
The hypothesis was formed that allocating land for the natural processes of dispersion of plants and animals, enhances the sustainability of the land and its use.

The influence of the medium computer in this study has been manifest. It has been realized that the electronic instruments are not only very useful in gathering land-data and processing these into information needed, but also that the instruments can gratifyingly be used for building decision support systems (DSS) for use in landuse planning.
The increase in capacity of computers in terms of calculation speed and data storage, for many years has been exponential. In recent years the possibilities for graphic display of spatial data has also increased largely. This fast evolution has resulted in an incorporation of computers within landuse planning and one can even notice a marked evolution in landuse planning itself. There now

is not only a growing tendency to gather more and different data (soil data, hydrological data, topographic data, biotic data, economic data, and the like) but also to approach land as an organic and dynamic object for which landuse planning has become a way of process-steering.

The result of the study engaged in, is a three-fold contribution to the toolbox of landuse planners in the strive for a better use of land. The three contributions, in sets of computer programs, all deal with the spatial aspects of landuse[4].
The programs developed, can be placed within the group usually addressed as Geographic Information Systems (GIS), due to data-base and other features for analysis and graphic presentation. The main value of the tools created, lies in the decision support quality they have, and which is based on mapping features, on display of relevant data, on the use of optimization algorithms and on the possibility of using the tools for impact analysis.

The contribution of the computer program AKCI to landuse planning (see chapter 3) is to be found in its features for the display of data of the so-called "cultuurtechnische inventarisatie". These are data-files with topographic and socio-economic data of land-development projects and used within landuse planning in the Netherlands. The program AKCI enables planners to interactively produce thematic landuse maps, as well as some tabular output.
The computer program INTRANET contributes to landuse planning with features for the prediction of the effects and the implications of changes within the rural road system (see chapter 4). The program copes with questions related to distances between the locations of landuses in study, to the accessibility of the country-side, to the determination of where to locate activities, and to the effect of changes in network and road construction.
The computer programs of ECONET contribute to the landuse planning with modules for the determination of the location of the ecological infrastructure (see chapter 5). The ecological network is based of the parameter distance and

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4 Due to a necessary curtailing in the research, the impression that landuse planning is dealing with spatial aspects of landuse only, may have arisen. In planning for landuse many other questions have to be dealt with as well. Landuse planning for more favorable soil and water conditions and that of many other is also part of the planning for a good use of land. In this study emphasis has been put on the more spatial aspects of land.

on the dispersion characteristics of the species involved.
Like in INTRANET, editing features make it possible to use the programs for impact analysis. The effects of changes in size and location of the habitat areas and those of the intermediate obstructions, can be predicted.

The tools developed, are decision supporters. They are meant to give planners the opportunity to pose what-if questions and to give help in getting answers to such questions. It is up to the landuse planner to pose such questions and to compare the calculation results presented by the tools. Chapter 6 gives a synoptic review of the use of the programs.

# 2. LAND, LANDUSE AND LANDUSE PLANNING

## 2.1 LANDUSE

### 2.1.1 Dynamics in landuse

Human activity in rural areas leads towards changes within the countryside. Such changes can be understood when it is realized that farmers are major agents of change. By planting and harvesting their crops, by manipulating forests, by raising and selling livestock, and by building farmsteads or by repairing roads, farmer's daily activities generate change. Simultaneously, many institutional activities take place, including changing acreage under specific crops and varying changes for forestry, for housing, for recreation, for transport, and other landuses.
Man also improves the conditions under which the land can be used. For instance by draining the land where it is too wet or by bringing water where there is little, man accelerates change. Where soil conditions are poor, the soil profile can be improved and wetlocks removed, again achieving improvement meanwhile accelerating change.
In the Netherlands for example, landuse has changed substantially during the last 50 years. Some of it this change can by itself be noticed when looking at the figures of the various landuse acreages. See Table 2-1.

Table 2-1. Distribution of landuses in the Netherlands, period 1900-1990 (in hectares).

| landuse | 1900 | 1920 | 1930 | 1940 | 1950 | 1960 | 1970 | 1980 | 1990 |
|---|---|---|---|---|---|---|---|---|---|
| nature areas | 9 | 17 | 15 | 12 | 11 | 5 | 5 | 5 | 4 |
| woodland | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| cultivated areas | 65 | 66 | 68 | 70 | 69 | 73 | 72 | 70 | 65 |
| other | 8 | 9 | 9 | 10 | 12 | 14 | 15 | 17 | 23 |
| total(x1000) | 3255 | 3261 | 3265 | 3275 | 3335 | 3550 | 3616 | 3662 | 3729 |

source: CBS.

Nature areas have decreased significantly since 1920, while acreage for agricultural purposes after a substantial increase at first, has returned to levels present at the beginning of this century. The use of land for the built-up area and for roads (the category 'other'), has strongly increased.

These changes in landuse are not only the result of changes in opinions about what landuses are needed, they are also a reflection of changes in the number of people engaged in different professions as a result of growth in societal organization and technological innovation. See also Tables 2-2 and 2-3.

Table 2-2. Labor volumes ($x10^3$) in enterprises, period 1925-1990, the Netherlands.

| year | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| 1925 | 2730 | 160 | | | | | |
| 1930 | 3050 | 170 | | | | | |
| 1935 | 3180 | 170 | | | | | |
| 1950 | 3853 | 582 | 1151 | 34 | 310 | 1304 | 392 |
| 1955 | 4016 | 532 | 1243 | 36 | 351 | 1385 | 469 |
| 1960 | 4182 | 465 | 1299 | 37 | 379 | 1454 | 490 |
| 1965 | 4502 | 388 | 1381 | 42 | 464 | 1711 | 516 |
| 1970 | 4696 | 329 | 1224 | 43 | 505 | 2028 | 567 |
| 1975 | 4670 | 299 | 1097 | 44 | 429 | 2164 | 637 |
| 1980 | 4807 | 278 | 1001 | 46 | 449 | 2319 | 714 |
| 1985 | 4686 | 269 | 916 | 46 | 343 | 2369 | 743 |
| 1990* | 4700 | 226 | 940 | 46 | 360 | 2400 | 740 |

(1) labor volume in enterprises, total
(2) agriculture and fisheries
(3) manufacturing, mining and quarrying
(4) utilities
(5) construction
(6) services
(7) government
* indicative
source: CBS.

From Table 2-2 a major downward change in labor volume within the sector agriculture (including fisheries) can be seen, while total labor volume has increased. This expansion of total labor is found in services (cat. 6) and government (cat.7). Similar data can be found for many other countries.
Table 2-3 shows that the number of animals has increased and that milk- and meat (cattle, pigs, chicken) production have gone up also. In general, production has become large-scale and has been intensified and industrialized.

The countryside, of course, is also subject to natural changes which occur without the interference of human beings. Examples include climatic events, growth and multiplication of flora and fauna and physical modifications of the landscape from erosion, earth quakes, volcanic actions, sea intrusion, storm and other less drastic forces. Within such autonomous dynamic settings, man is ..

Table 2-3. Production data, period 1825-1990, the Netherlands.
(animals x1000)

| year | horses | cattle | pigs | chicken | milk x1000 ton | eggs x1000 ton |
|---|---|---|---|---|---|---|
| 1825 | 214 | 1003 | | | | |
| 1855 | 234 | 1254 | 236 | 2000 | | |
| 1880 | 252 | 1470 | 335 | 2000 | | |
| 1900 | 295 | 1656 | 747 | 3000 | | |
| 1910 | 327 | 2027 | 1260 | 10000 | 2706 | |
| 1920 | 364 | 2063 | 1519 | 10000 | 2513 | |
| 1930 | 299 | 2366 | 2018 | 24000 | 4418 | |
| 1940 | 326 | 2690 | 1288 | 35000 | 5194 | |
| 1950 | 253 | 2723 | 1864 | 23000 | 5771 | |
| 1960 | 187 | 3507 | 2955 | 42000 | 6838 | 284 |
| 1970 | 86 | 4314 | 5533 | 55000 | 8252 | 263 |
| 1980 | 67 | 5226 | 10138 | 81155 | 11844 | 539 |
| 1990* | 50 | 4926 | 13909 | 92765 | 11375 | 675 |

* indicative;
source: CBS

able to manipulate and give shape to the land in the sense of creating new physical and biological situations.
The activity by which the natural state of the landscape changes, takes different names, according to the type of actions which man practices. For example, it is called farming when it is looked upon from the point of view of agricultural production, or it is called forestry when growing trees is the purpose; and the activity in both cases repeats itself season after season.
However, where changes in the natural landscape become a one-time operation and are directed towards changing the conditions under which a particular landuse (for example farming) can be carried out, such changes are called land-and-water development, or landscaping. Such changes then become a multiple landuse planning item. Activity has then surpassed the point of being just a seasonal investment or a single-purpose planning effort.

When changing land takes an organized form, that is where many people participate in a communal project, the changes in landuse and landuse conditions become of common public interest. Therefore, such projects often are governmentally guided, if not initiated.

Table 2-4. Some data on land-development projects 1945-1990, the Netherlands.

| year | (1a) | (1b) | (2a) | (2b) | (3a) | (3b) |
|---|---|---|---|---|---|---|
| 1945 | 35870 | 32 | - | - | 23780 | 50 |
| 1950 | 85730 | 63 | - | - | 42850 | 67 |
| 1955 | 169250 | 69 | - | - | 89440 | 122 |
| 1960 | 274730 | 91 | - | - | 134130 | 151 |
| 1965 | 434140 | - | 394100 | - | 226470 | - |
| 1970 | 560010 | - | 494890 | - | 368100 | - |
| 1975 | 522060 | - | 491980 | - | 612970 | - |
| 1980[1] | 526680 | - | 363300 | - | 792700 | - |
| 1985 | 653500 | 107 | 286790 | 65 | 837020 | 345 |
| 1986 | 624810 | 101 | 288200 | 64 | 900080 | 335 |
| 1987 | 592740 | 99 | 311410 | 70 | 936620 | 360 |
| 1988 | 591990 | 104 | 315480 | 71 | 959800 | 364 |
| 1989 | 541906 | 99 | 331219 | 77 | 1023366 | 373 |
| 1990[1] | 569696 | 105 | 338430 | 79 | 976272 | 369 |

(1a,b) total ha and number of areas under construction
(2a,b) total ha and number of areas in preparation
(3a,b) cumulative ha and number of projects finished
- values not known
source: Government Service for Land and Water Use

Table 2-4 indicates the possible size of such organized change in landuse and includes data on land-development projects in the Netherlands, under patronage of its Government Service for Land and Water Use. From this Table[1] it can be seen that land-development comprises a major importance within a country like the Netherlands, which comprises some 3,700,000 ha of land of which some 65% currently is in agricultural landuse (Table 2-1).

1

As of 1980 the data columns 3a and 3b are not consistent with those earlier because the Government Service of Land and Water Use reports data of projects from the so-called 'list of financial settlements', rather than from the list 'completely finished'.
As of 1990 the areas redeveloped under the special redevelopment laws concerning the province Zeeland (i.e. those of '47 en '53) have been omitted from the census.

### 2.1.2 Multiple landuse

Although farming is the most dominant type of landuse in rural areas, it is not the only landuse. Aside from giving opportunities for agricultural production, rural areas give space for housing, for transportation, for nature conservation, for the enjoyment of landscape, and for other forms of recreation. Rural areas in fact, should explicitly be seen from an interdisciplinary point of view, and, within landuse planning, treated as such.
Although terms like production and productivity fit easily into concepts related to farming, these terms can be applied to other landuses. For example, whatever is planned for, people like to see their efforts rewarded with high returns, even if those returns are public rather than private. Thus, there is no real difference between planning, developing and managing land for agricultural purposes and that for other forms of landuse.

A well known Dutch example of land development for multipurpose use was commented on by e.g. Steenhuis (1986) and van Lier (1989), and is shown in Table 2-5.

Table 2-5. Landuses planned in four reclaimed polders in the Netherlands.

| Polders | current area ha | development period | ----------landuses --------- 1) farmland 2) residential (1) | 3)wood/wetland 4) roads, canals (2) | (3) | (4) |
|---|---|---|---|---|---|---|
| Wieringermeer | 20,000 | 1929-1940 | 87% | 1% | 3% | 9% |
| NO-polder | 48,000 | 1942-1962 | 87% | 1% | 5% | 7% |
| E. Flevoland | 54,000 | 1950-1956 | 75% | 8% | 11% | 6% |
| S. Flevoland | 47,000 | 1968- . | 50% | 18% | 25% | 7% |

Though the polders have primarily been created to enlarge agriculture acreage, changing social and economic priorities have reduced farmland in favor of land for residential use and 'nature' purposes. Thus, the importance of a multi-functional approach to landuse has been appreciated by many.

Not all land-development activities occur on such scales or effect the public interest so evidently. This does not mean, however, that individual landuse and

development activities do not have public effects. For example, when soil is improved for the sake of achieving better drainage conditions, the excess effluent is likely to be passed on to neighboring land. Experience has shown that such problems are best solved through public involvement.
Other landuse activities borne of the human effort to overcome environmental constraints can easily be given. For example, how does a country deal with intrusions by the sea, with threatening salinization, with the pollution of water, soil and air? How does society deal with sonar pollution caused by traffic or with excess traffic itself, with stench, with pollution of views? How does it create sufficient access to land without causing unwanted side-effects? How is mobility demand mitigated?
Landuse planning is directed at solving such constraints on a broad scale, while not over-focussing on singular causes and effects. What is needed is focussing on the interactions of these constraints, with efforts "more to societies' liking and to systems less threatening to global life-support" (Clark, 1986).

In many cases the time needed to prepare and execute landuse plans is long. Land-development projects in the Netherlands for instance, require up to 13 years for preparation, and some 15 years for implementation. Such projects in total thus take over 25 years (van Wijland, 1989). Some reasons for this, are (Burger, 1989):

- capacity problems arising from an increase in the number of projects with an increased complexity (that is, with an increase in landuses and the parties concerned);
- shortage of money resulting in a delay of activities;
- political indecisiveness.

In view of the dynamics in economic, political, social and technical constraints, such lengthy projects require far too much time and therefore are unacceptable. For example, the preparation of land-development plans in the Netherlands presently involves, among other things, a master plan for the road and water infrastructures and one for the landscape. These are based on four 'sector'-notes; one for the sector agriculture, one for the sector nature, one for the sector landscape and one for the sector recreation.
These sector-notes mainly consist of claims for land along with others for favorable conditions pertinent to the concerned sector. Little or no consideration is given to the possible impact (the realization of) these claims have

upon the other landuses, let alone the fact that these all have to be integrated into one plan. Today, however, it is realized that more attention should be given to the (inter)relations between the various landuses (CMLI, 1990), meaning that new planning concepts and techniques are necessary. Meadows (1972) has put it like this: "..our usual methods for analysis, approaches, policy and system of government fail if they are confronted with ... complex situations".

## 2.2 LANDUSE PLANNING

### 2.2.1 Landuse planning activities

Landuse planning deals with envisaging what conditioning of land is necessary for what pre-determined purposes. It therefore deals with optimization of land conditions for one or more (and usually complex) interrelated landuses.

To understand the notion of landuse planning, it is necessary to make a distinction between physical planning, planning for land (re)development and planning for land-management. See figure 2-1.

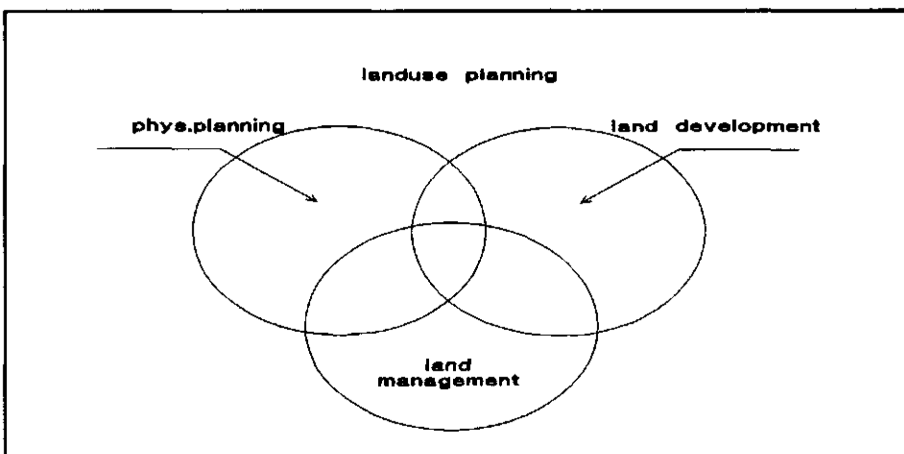



Figure 2-1. Landuse planning activities.

On this distinction, physical planning is seen as the activity which seeks and determines proper landuses, while planning for land (re)development is the detailing of plans for the transformation of present land conditions into those landuses determined by the physical planning activity. Finally, planning for land-management is the seeking of optimal use of land without major (re)development and shifts in landuses. Many countries are engaged in landuse planning under this model.

In the Netherlands land-development has reached the point where it is the legally sanctioned mechanism used to reorganize, reparcel and reallocate farmland, and it takes place within the context of comprehensive policy planning. There the principle aim of the national land-development policy is the development, within the overall framework of governmental policy, of parts of the rural area in accordance with the functions attached to them and to their mutual interconnection, in such a way that the area's social significance can be maximized as much as possible (Grossman, 1988).

While it is useful to think of landuse planning in terms of the simple sequence mentioned above, the planning process in practice is somewhat more complicated. Landuse planning must be thought of in terms of a cybernetic process, not necessarily beginning with physical planning activities. See also figure 2-2.

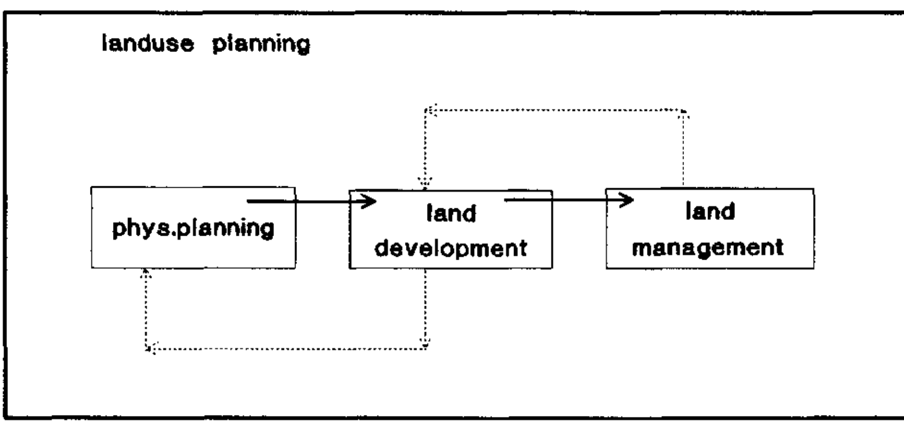



Figure 2-2. The landuse planning process.

The determination of future landuses depends on whether a transformation of present conditions (such as soil and water conditions) can be achieved under which costs and benefits. On the other hand, the determination of the transformation activity requires knowing for what purposes and landuses and under

what constraints the technical detailing should take place.
Manning (1991) distinguishes three types of problems which can arise from changes in the land base supply or in demands on that base:

i) problems of allocation of land between users and user sectors
ii) problems of management of land once it has been allocated among sectors
ii) problems of externalities or intersectoral impact involving disruptions caused upon one user or by others.

The nature of information needed to address these problems, includes (after Manning, 1991):

a) variables identifying the quantity of different land types and their different capabilities;
b) variables identifying the quality of land with respect to certain biological and physical factors;
c) variables identifying the geographic location of land;
d) variables identifying the current pattern of landuse.

### 2.2.2 Landuse planning objectives

Human beings, whether individual or collective, essentially aim at achieving progress. This process, however, is constantly influenced by a number of permanently changing needs, including the aspirations and dexterity of individuals and the (non-)availability of resources. The complexity of all this requires a permanent reflection upon objectives and needs, and a monitoring of processes and changes in conditions of the land.

Related to rural landuse in the Netherlands, the following general objectives in relation to agriculture and other related rural landuse have been set (Min. van Landbouw, 1982):

- to maintain and improve the competitive economic position
- to balance regional income differences (for farmers)
- to improve working conditions
- to enlarge landuse possibilities in view of long-term use
- to improve the quality of the landscape
- to bring about a good and safe road infrastructure
- to improve water management, aimed at integrated water control
- to contribute to good living conditions

In the Netherlands these goals are pursued by means of a permanent upgrading of land resources through reconstruction of the infrastructure. This reconstruction is achieved by upgrading soil and water conditions, by upgrading accessibility, by relocation of landuses and by reallocation of means.
The reconstruction of land and its use involves the rearrangement of property (ownership and use), the regulation of commerce and industries, the planning of economics, the guiding of many interrelated activities and often the solving of many dissenting interests.

Answers have to be given to questions like where, how, when, what has to be done. From a research point of view, these questions relate to what method and what technique can be employed or should be developed for a better understanding of present constraints and landuse possibilities. Landuse planners, as a professional group, are responsible for examining some of these questions, for providing insight into such matters and for presenting alternative solutions for problems envisaged.

## 2.3 LAND

### 2.3.1 Concepts of Land

Land, the object of landuse planning, can be referred to as the complex of soils, waters and climate upon which life occurs. In the less restricted view one can include all biological life. By taking even a broader view, society itself can be included and the total looked upon as an intricate complex consisting of three separate, though interlinked, (sub) complexes. See figure 2-3.

Daily life shows us that man individually and collectively, is greatly influenced by the physical and biological conditions of the land. Without soil, water and air there is no plant and animal life. And, without the biological life, there can be no shaping of homesteads, holdings, communities, and no forming of a society as a whole. Figure 2-3 is a depiction of this interpretation of land, showing interrelationships between the complexes.

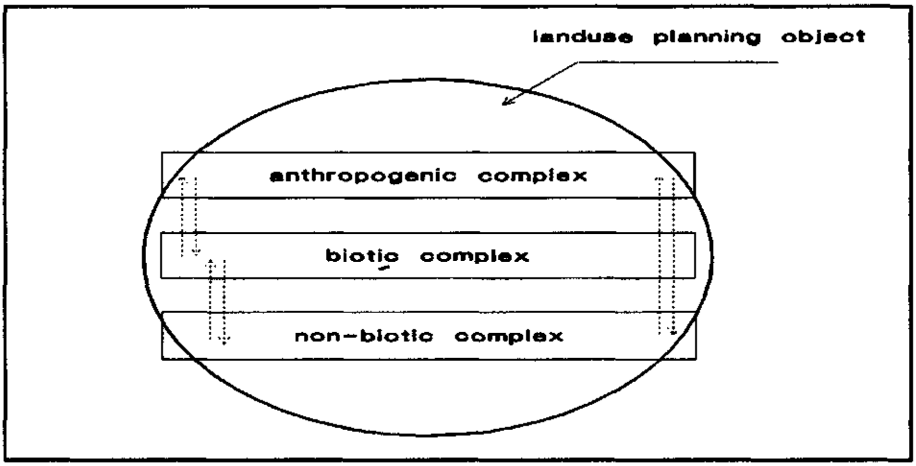



Figure 2-3. An interpretation model of land.

With Table 2-6, a classification of the three complexes (after Boulding, 1956) is given, distinguishing nine interrelated levels of interest.
The bottom system, the physical/mechanical system as Boulding calls it, is most basic, and literally is fundamental to the other systems on top. Without such a physical fundament, no upper systems can exist.

Table 2-6. A classification system of the universe (after Boulding,1956).

| | |
|---|---|
| | 3.3 transcendental level |
| 3. human/social systems | 3.2 social level |
| | 3.1 human level |
| | 2.3 animal level |
| 2. biological systems | 2.2 plant level |
| | 2.1 cell level |
| | 1.3 thermostatic level |
| 1. physical/mechanical | 1.2 clockwork level |
| systems | 1.1 framework level |

Looking within the three systems/complexes, the bottom level is the static structure, to be seen as the framework upon which is superposed the level with pre-determined physical/chemical movements. These movements are subject to regulators, which might be addressed as thermostatic actors.
The biotic complex superposes the abiotic system. Self-maintaining rules apply, and genetic-societal rules typified by the plant, can be distinguished from that

of the cell life form. Animal-life follows, distinguishable from plant-life due to characteristics like mobility and self-awareness.
The anthropogenic complex is the third system/complex distinguished. Individuals, characterized as life-form with language and reason, form the human-level with possibilities for societal organization, characterized by passing on to others, matters like values, notions and beliefs.
Although the several systems/complexes and levels by themselves can be thought of as systems, the total is to be seen as a dynamic cybernetic system and not necessarily in equilibrium. See figure 2-4 showing the relationships referred to in a cybernetic display.

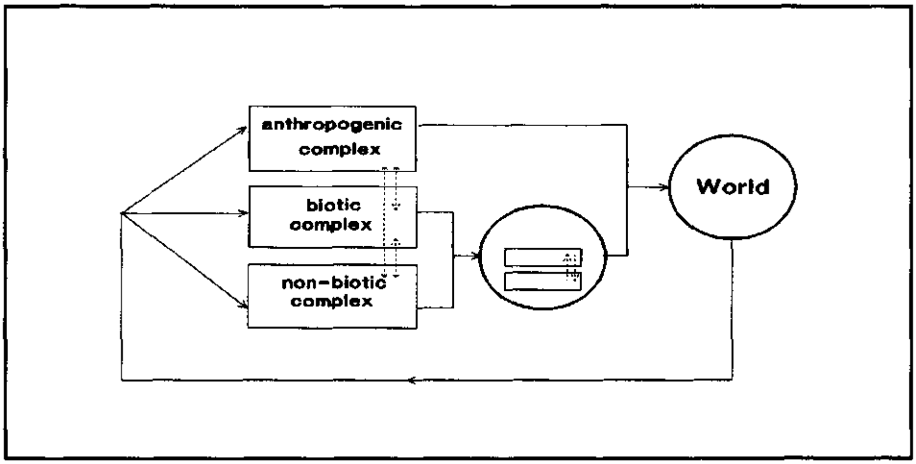



Figure 2-4. The interrelationships of abiotic, biotic and anthropogenic complexes.

With land seen as a dynamic complex with interrelations between the three sub-systems (those with physical, biological and social phenomena), it can be understood that performances of sub-systems influence other sub-systems. Output for the one is input for the other.
Figure 2-5 displays the three complexes in more detail, as far as the interrelationship between various forms of landuse is concerned. Each matrix-'node' is part of the 'weave' and in such a context, a landuse planning item.

The viewing of land as a dynamic, cybernetic complex, is helpful in understanding necessary landuse planning actions. It is also needed, if steering the processes within this complex is the ultimate objective of landuse planning.

Rainfall, sunshine, wind movement and other processes within systems of complex 1, influence plant and animal growth (processes within systems of complex 2). Many other such examples can easily be given. With shortcomings in soil qualities, with unsatisfactory water conditions and with a poor biological functioning of the environment, there are few possibilities for societies to flourish, yet people have long noticed that changing unfavorable conditions can improve (agricultural) output. This awareness has lead to substantial land development activities as well as to the cultivation of new lands through reclamation. Such activities, however, have not always turned out to be advantageous, and many examples can be given where ultimately land degradation with loss of productivity has occurred.

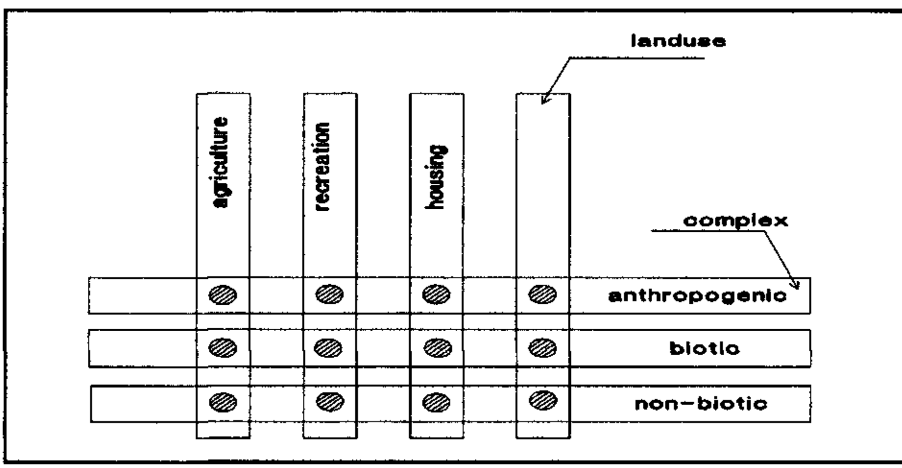



Figure 2-5. A matrix display of the interrelationship between various forms of landuse and system-levels of the landuse planning object.

Brown (1984) has estimated the worldwide loss of soil by erosion (Table 2-7), and included an estimate of erosion due to mismanagement in a number of countries (Table 2-8). The Worldwatch Institute (Brown,1991) presently estimates this loss to be 24 billion tons yearly, approximately the amount covering the complete wheat area of Australia. The institute estimates the productivity loss to be approximately 6 million ha/yr.

Barney's report, 'The Global 2000 Study' (1980), shows the effect of deforestation on a number of continents, including the effect it has on the extinction of species within the ecosystem (Table 2-9). It is presently well known that loss of forest-cover increases flooding, yet damaging practices continue causing the rate of forest-cover loss to be some 17 million ha/yr, approximately the size of Austria.

Table 2-7. Cropping systems and soil erosion worldwide (after Brown,1984).

| cropping system | average annual loss of soil (tons/ha) |
|---|---|
| corn, wheat and clover rotation | 2.7 |
| continuous wheat | 10.1 |
| continuous corn | 19.7 |

Table 2-8. Estimation of annual erosion on cropland (after Brown,1984)

| | ha cropland ($x\ 10^6$) | soil loss ton $x10^6$ | ton/ha/yr |
|---|---|---|---|
| USA | 167 | 1,500 | 9.0 |
| Soviet Union | 251 | 2,000 | 9.2 |
| India | 140 | 4,700 | 33.6 |
| China | 99 | 3,300 | 33.3 |

Table 2-9. Extinctions of species worldwide implied by the Global 2000 study's Projections (after Barney,1980).

| | present species ($x10^3$) | projected deforestation (%) | loss of species (%) | extinction ($x10^3$) |
|---|---|---|---|---|
| a. areas with low deforestation | | | | |
| Latin America | 300 - 1,000 | 50 | 33 | 100 - 133 |
| Africa | 150 - 500 | 20 | 13 | 20 - 65 |
| South and SE. Asia | 300 - 1,000 | 60 | 43 | 129 - 430 |
| b. areas with high deforestation | | | | |
| Latin America | 300 - 1,000 | 67 | 50 | 150 - 500 |
| Africa | 150 - 500 | 67 | 50 | 75 - 250 |
| South and SE. Asia | 300 - 1,000 | 67 | 50 | 150 - 500 |

The task of steering the interrelations between land practices towards high levels of societal satisfaction, is a process of organizing the "physical" parameters as well as those more social. As Kleefmann (1984) implies, the object of research in landuse planning is to blend the complex entities 'physical organization' and 'social organization'. See also figure 2-6.

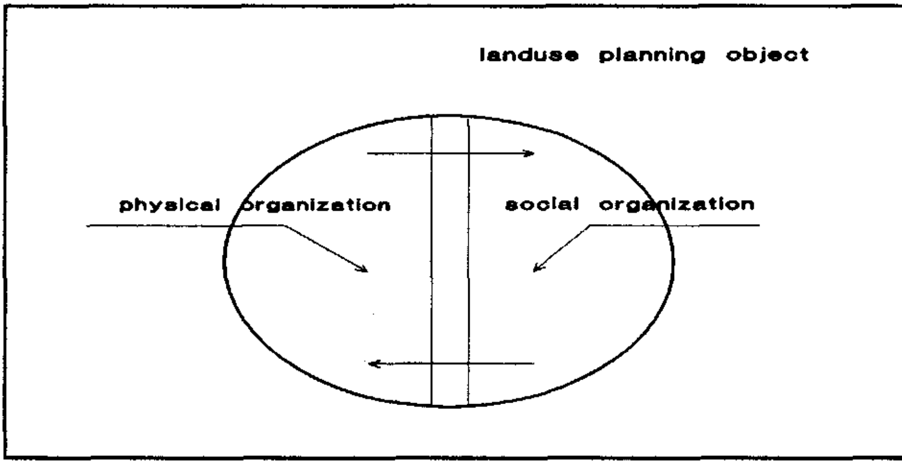



Figure 2-6. An interpretation of land as a physical and social organization complex (Kleefmann (1991), adapted).

How social organization relates to processes in which normative ideas and judgments are involved, is commonly understood in social science circles, yet, we can find examples of very unbalanced and disturbed situations all over the world. There is a growing acceptance of the idea that mankind cannot continue allowing land to turn into deserts, to become salinized or otherwise polluted, and that we cannot continue the loss of tropical forests, of wildlife species and of other crucial environmental matters. At issue for landuse planners is the finding of ways for designing appropriate use of land. Mankind cannot continue to offbalance land in the strive for bigger, better and more without factoring in the costs of such actions. Today the challenge is to create high-level existences within sustainable settings. This laudable goal demands new planning techniques and new --perhaps revolutionary-- views on landuse.

### 2.3.2 Social levels

Landuse planning is an old 'game'. People around the world expend effort to manage their environment to make the best of it. History shows all kinds of efforts exerted by many generations in pursuit of optimum landuse. Some of these efforts have proven to be of great benefit, others have turned out to have high social or economic costs.

There is no doubt that environmental constraints have limited how people conduct their lives. There is also no doubt that lifting these constraints through technological or organizational innovation has allowed social development.

It should be noted as a system-characteristic in its widest context, that new generations will have to proceed with what has been passed on to them by their predecessors.

Figure 2-7 diagrams the interrelationship between various levels of planning based on social territory. For landuse planning, the interrelated levels include individual, family, neighborhood, community, regional, national, hemisphere and global levels. These social levels can be seen as levels on which landuse planning is to be carried out while keeping in mind the relationships of one level to another.

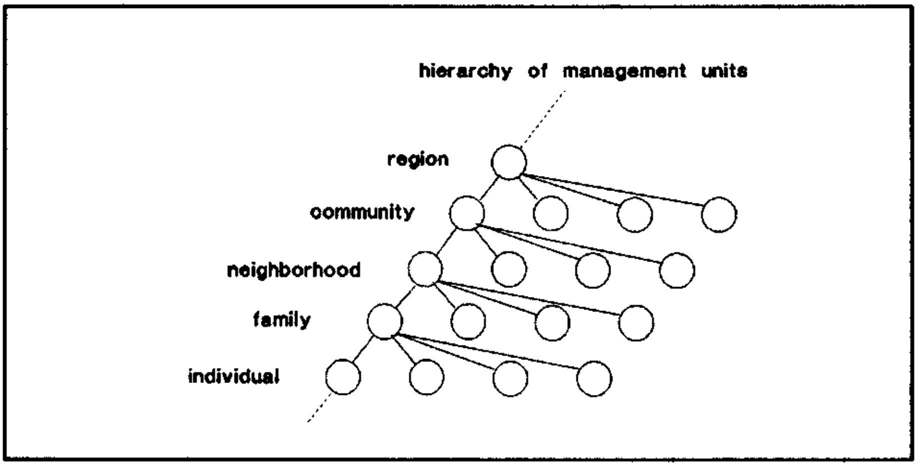



Figure 2-7. Several interrelated planning levels, based on social territory.

Clark (1989a) describes the present management situation as follows:

".. the management problem has been transformed today by unprecedented increases in rate, scale and complexity of interactions between people and their environments". Mankind no longer can limit debate to local incidents concerning individuals, but must expand his scope to manage earth on a more macro scale. Sustainable developments can be sought, which require the pursuit of "paths of social, economic and political progress without compromising the ability of future generations to meet their own needs" (Brundtland, 1987). If such wishes are to be translated into specific actions, specific proposals must be designed to shape land and to use materials, energy and labor. Such actions must be taken on the individual level as well as on the collective levels. Clark (1989b) states: ".. there is a need for relating local development action to a global environmental perspective."

Depending on the impact of change, its effects in terms of land, social, political and economic scope, differ. The impact of industrial, economic and political organization often is more global than individual. Meanwhile sustainability is obstructed more by social, institutional and political forces than by technical ones (MacNeill, 1989) or even by natural processes (Crosson, 1989). Thus, with Clark (1989c), it can be stated there is a need for:
- a basic knowledge of how the global environment works;
- making the information upon which individuals and institutions base their decisions more supportive of sustainable development objectives;
- the invention and implementation of technologies for sustainable development;
- the construction of mechanisms at the national and international level to coordinate managerial activities;
- the desire and ability to reflect continually on the values and objectives which guide our efforts.

## 2.4 THE LANDUSE PLANNERS' RESEARCH CHALLENGE

### 2.4.1 The ever shifting object

Planning, in terms of shaping and conditioning the environment, can be seen as an activity transforming a situation A into a different situation B.
The result of the shaping is a new combination of the three complexes (physi-

cal, biological and social), each with new levels of activity as compared to the previous combination. See figure 2-8, seemingly without changes.

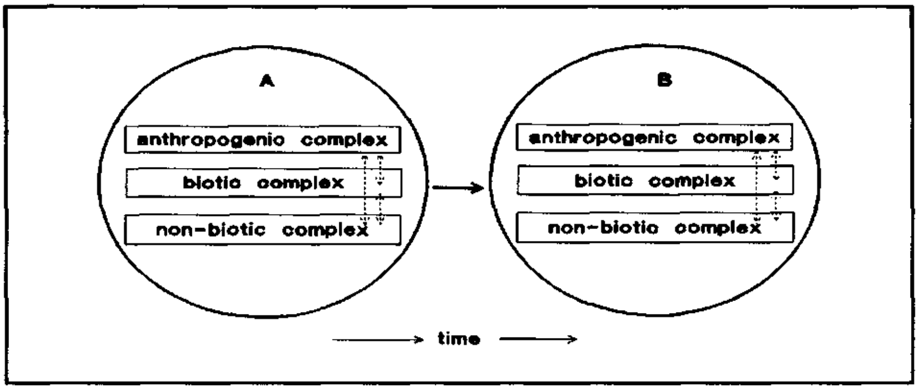



Figure 2-8. Transition of landuse situation A into situation B.

This shaping is a continuous process, with each new situation representing a new starting point (in time) for further activities, as figure 2-9 demonstrates. Within this process there are processes beyond the direct control of man, which means that planning for future situations is more than merely a question of social management and technical know-how.

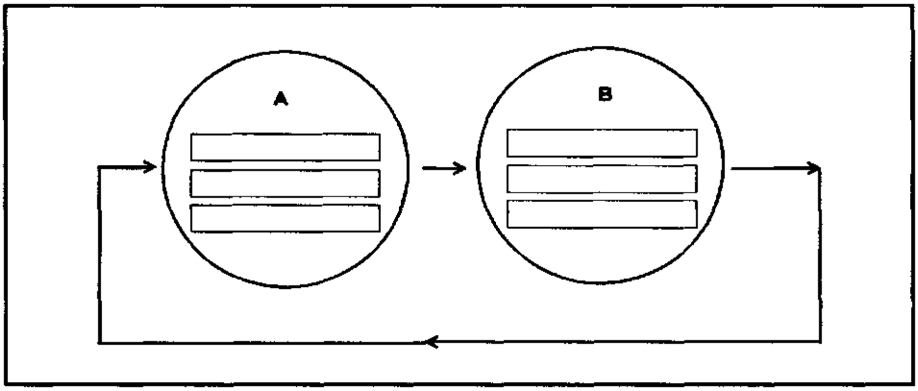



Figure 2-9. Landuse situations A and B seen as part of a continuous cybernetic process.

Landuse planners nevertheless have the responsibility of demonstrating which

new landuses are wise to pursue, and by what effort and what method. Such demonstrations must embrace the fact that different people judge differently, meaning that people affected by planning must work through the spectrum of outcomes before choosing the best alternative.
For landuse planning, therefore, understanding the physical and biological processes is fundamental in order to appreciate the impacts of human interference, past and present. It is necessary to make explicit and understandable any expectation of what is going to be or might be in the future.

For such planning there is at least a need for:
- soil-data
- hydrologic data
- topographic data on roads, waterways, field sizes and form, buildings, sociographic units, and the like.
- landuse data on different anthropogenic landuses
- landuse data on woodlands, brooks, moors, wetlands, and other units with natural and semi-natural landuse
- data on plant and animal life
- socio-economic data

Geographic Information Systems (recent developments in computer technology which are increasingly used in landuse planning research) have superb capability for displaying the various entities. These systems present planners with possibilities of better use of research data than ever before. A total, systematic description and derived understanding of all levels of interest, however, is not feasible. Knowledge will always remain incomplete, requiring great care in the use of available data.
Choosing for certain use(s) not only depends on incentives for change (visioned by opportunities of a physical and biological nature, as well as on individual values, objectives and technical knowledge) it also depends on human phenomena like the social, political, institutional and managerial organizations within society.

Planning for the future involves making choices now. It is a process involving individual and collective thinking, whereby projections of new landuses, conditions and processes, are envisaged, rejected, reshaped and developed (Kleefmann, 1984).

Physical planning, in this context, can be seen as an organized mean along which individuals and groups of people as a whole can come to some understanding of what to do for the welfare of individuals, groups and society as a whole. In terms of technical rationality and engineering, it of course deals with the physical and biological manipulation of land.
In this same context, planning for land-development is to be seen as the organization and the development of the technical details of plans for new and better landuse. It is a cybernetic activity in harmony with and attuned to the activities of physical planning and land-management; neither one goes without the other.

### 2.4.2 Forecasting

Projections of what is wanted, and how future conditions and processes will be, are needed. Such forecasting is necessary, not so much for knowing the future itself, but for an understanding of what might be possible in view of man's ability to influence the shape of the present.
Future situations however, by definition, are situations not yet present and consequently cannot be monitored like present situations. However, assuming that present conditions can be known and future conditions can be shaped, it is necessary to estimate and weigh what lies ahead in order to present alternatives which might be. Only then, with a reasonable understanding of underlying processes, individual and societal objectives can be set along with ways to achieve them.

Following van Doorn and van Vught (1981), this type of research might include:

- 'trend' forecasting
  in which the extrapolation of trends leads to finding alternatives
- speculative forecasting
  which leads to understanding future times as a result of introducing innovations which have no historical precedent
- explicative forecasting
  in which emphasis is laid on specifying paths and future situations in order to get a better understanding of possibilities
- integrative forecasting
  with emphasis on research into the implications and relation of separate

forecasting researches.

Using the typology of Maruyama (Bennet, 1987) research can be induced by a variety of motives, leading to:

- defensive-reactive forecasting
  with intentions to create forecasts based on preservation of old patterns
- instrumental-reactive forecasting
  with intentions to use new tools for old purposes
- adaptive-reactive forecasting
  directed at modifying culture in order to adapt to technological changes
- goal-generating forecasting
  with purposes of adapting and developing technology towards targets set

By tuning into various types of forecasting, a spectrum of possibilities can be created upon which choices can be made for a course to be taken.

### 2.4.3 Research and planning

**Modelling**

In order to understand the future, one must understand the present through processes of monitoring and modelling.

The use of models for research on the effect of changes in values of parameters leads towards a valuable understanding of what can be expected in real life situations, if similar changes were to take place. Modelling lends a useful basis for the creation of plan-proposals.

Thinking in terms of possible modelling, Jenkins (1976a) made the following hierarchy:

1a - descriptive models
  models directed at providing qualitative description and insight

1b - predictive models
  models intended to predict the performance of a system

2a - mechanistic models
  models based on mechanisms by the way the system looked into, behaves

2b - empirical models

models based on fitting input to output obtained by the system that is described

3a - steady state models

models based on average performances

3b - dynamic models

models allowing performance of the system to fluctuate in reference to time

4a - local models

models based on behavior of sub-systems, the sub-system seen as part of a larger system

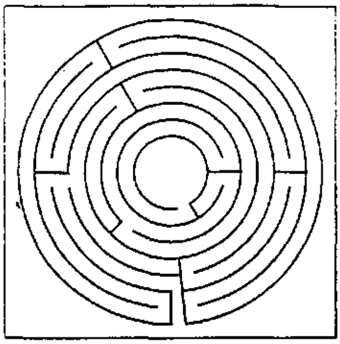
4b - global models

models based on behavior of the overall system

The qualifications of models are not uniquely attributal; models can have several of these qualifications at the same time. The list refers to varying aspects and varying intentional use, and can be used as a guideline for research within landuse plan-creation aiming at finding the better plan.
Modelling requires a (normative) interpretation of reality and a construction of the model itself. Bad monitoring of the real world can lead to wrong data, to wrong modelling and to misinterpretation. Models themselves require monitoring and an analysis of output as well. Usually much effort has to be spent to get levels of realistic behavior. Model interpretations are necessary, judging whether the outcome sufficiently fits reality. If not, model parameters should be changed or even new models made. See figure 2-10.

Modelling can lead to useful landuse proposals, when the effect of changes within the model are similar and comparable to those expected within the real world. Models thus can be usefully used as feedback tools.
If planners, by means of modelling, wish their proposals to reach acceptable levels of reliability, models have to be reasonably accurate and resemble the real world situation. Inaccuracies which are due to shortage of knowledge and to modelling, are to be acknowledged explicitly by planners and decision makers.
From a planning point of view this can mean exercising sensitivity analysis on the parameters within the created models. As Jenkins (1987b) puts it, there is a need:

- to understand the extent in which the optimum found (in the model),



**STELLINGEN**

1. Landgebruik moet opgevat worden als een totaalproces van meerdere, van elkaar afhankelijke en elkaar beïnvloedende, veelal ruimtelijk verspreid liggende vormen van grondgebruik.
(dit proefschrift)

2. Het structureren van de abiotische omstandigheden, het aanpassen van de ruimtelijke maatvoering van gebruikseenheden en het dagelijks gebruik van grond beïnvloeden de politieke-, sociale-, demografische- en culturele dimensies van de samenleving.
Dergelijk activiteiten vragen een breed maatschappelijk draagvlak èn een evenwichtige afstemming tussen rechten en plichten van betrokkenen.
(dit proefschrift)

3. Voor een correcte belangenbehartiging dient ook het landgebruik buiten de ruimtelijk eenheid waar landinrichting plaatsvindt, actief betrokken te worden. Dit dient tot uiting te komen in de landinrichtingsprocedure; bij de voorbereiding van plannen, bij de analyse van de effecten van voorgestelde maatregelen èn in de besluitvorming.
(dit proefschrift)

4. Gezien de toename in intensiteit van antropogeen landgebruik dient de planning van landgebruik zich, méér dan voorheen, te richten op een systeemanalytische benadering van de gebruiksvormen.
De zogenaamde Cultuurtechnische Inventarisatie-bestanden lenen zich voor de vastlegging van data voortkomend uit dergelijk onderzoek en zullen dan voor planningsdoeleinden in belangrijkheid toenemen.
(dit proefschrift)

5. De beoogde landbouwkundige winst als gevolg van het slechten van wegen, weegt niet op tegen het verlies aan recreatieve- en natuurwetenschappelijke waarden.
(dit proefschrift)

6. Bij planning in landinrichtingsverband dienen wegenstelsels bezien te worden op hun verbindings- en ontsluitingsmerites voor verschillende vormen van gebruik. Daarbij dient eveneens overwogen te worden de verschillende grondgebruiken naar gunstiger ligging te verplaatsen.
(dit proefschrift)

7. Voor de planning van meervoudig grondgebruik is het noodzakelijk dat Geografische Informatie Systemen worden uitgebreid met beslissingondersteunende modules. De rol van optimaliseringsmodellen en -technieken dient in deze richting krachtig te worden uitgebreid.
(dit proefschrift)

8. Naarmate de rekensnelheid van computers toeneemt, is het onderzoek naar exacte oplossingsmethoden van complexe vraagstukken, relevanter dan soortgelijk onderzoek naar heuristische methoden.
(dit proefschrift)

9. Ter vermijding van begripsverwarring dient het in de landinrichting gebruikte woord **evaluatie**, doelend op het inschatten van op te treden effecten als gevolg van voorgestelde landinrichtingsmaatregelen, vervangen te worden, bijvoorbeeld door het woord **effectverwachting**.
(dit proefschrift)

10. De bestuurderen van de Landbouwuniversiteit dienen serieus te overwegen de huidige naam van de universiteit te verkorten tot Universiteit Wageningen, danwel daaraan een persoonsnaam te verbinden.

11. Er dient ten spoedigste een aan televisie en radio toe te voegen module te worden ontwikkeld, die de ontvangst van reclame-uitzendingen, naar wens van de kijker/luisteraar, kan blokkeren.

12. Het oefenen van geduld in het kader van de bestrijding van milieuvervuiling, is geen schone zaak.

13. Het is te verwachten dat in de voormalige Oostblok-landen de roep om te komen tot een geleide economie, vooralsnog zal toenemen.

**C.R. Jurgens**
**Tools for the spatial analysis of land and for the planning of infrastructures in multiple-landuse situations.**
Wageningen, 12 juni 1992

changes due to changes in the parameters

- to understand the sensitivity of the criterion to the various assumptions made in the design
- to understand the extent of uncertainty in the forecasts taken as model-assumptions.

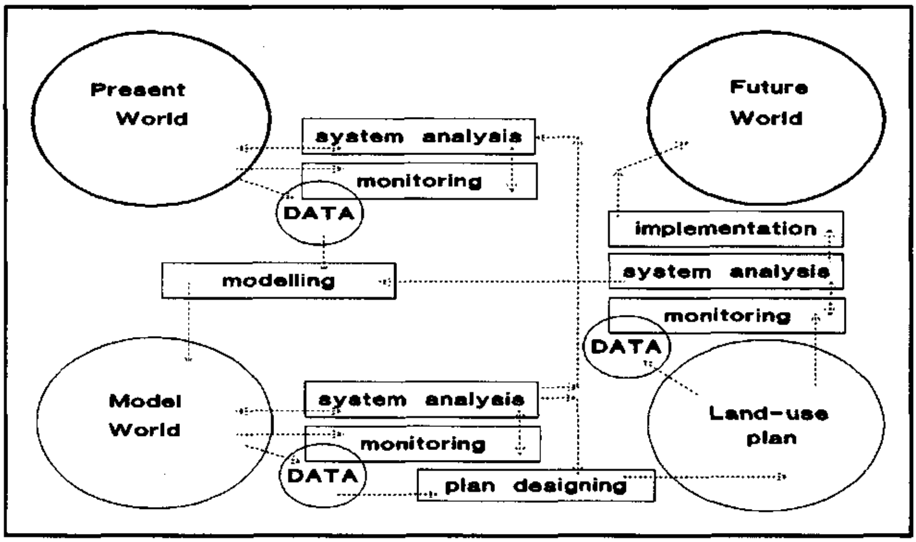



Figure 2-10. A diagram of a simplified cybernetic landuse planning process with various activities and stages of result.

**Impact analysis**

As stated earlier, landuse planning not only requires looking forward but also selecting the best means for achieving conditions favorable for future landuse. It also includes the determination and description of those conditions themselves. Therefore, the process has to put forward questions such as: What kind of landuse is wanted? What kind of landuse is possible? How much land is to be used for what landuses? For landuse planners there is the challenge of how to go about this process.

Landuse plans are seldom made along specific planning procedures. Often plans are grasped 'out of the air', the makers not exactly being able to tell why and how these plans came about.

Whether made along specific procedures or not, every plan-proposal is to stand

the test of whether it is good or bad. The planning process has to include a method by which one can come to a judgement of whether to proceed or to drop the proposal for a better one.
Aside from the technical difficulty of how to carry-out an impact analysis, a major drawback is that, although such an analysis makes it possible to choose between alternatives, the process itself does not generate proposals. The outcome of such an impact analysis by itself leads to the better plan, but only in as far as conceptual thinking has led to alternatives to be screened.
A possible way-out for this dilemma can be sought by introducing feedback of outcomes of such analysis into the creative part of the planning process.

**Feedback**
If the planning process could be shaped so that it systematically operates landuse plan proposals, it would make feasible the systematic exploring and analysis of new landuse possibilities. Today it seems, that the combination of monitoring, modelling, impact analysis with feedback, presents the best way to find the better landuse plan. When it becomes possible to merge the models with plan-generating techniques, the technique of landuse planning will have advanced to a new stage.

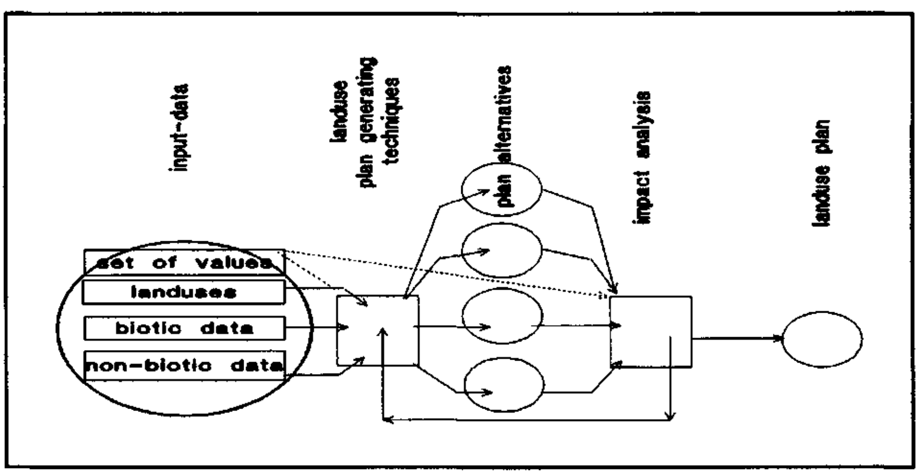



Figure 2-11. A simplified landuse planning procedure showing phases of creation, impact analysis and necessary feedback.

Figure 2-11 shows a diagram in which on the basis of available land-data and their attached values, such landuse plans can be developed. Using impact analysis techniques involving the same set of values used while generating the proposals, a preliminary plan is induced. By way of the feedback system the process is repeated, leading to a final landuse plan worth implementing.

## 2.5 COMMENTS UPON AND EXAMPLES OF THE LANDUSE PLANNING IN THE NETHERLANDS

### 2.5.1 An historic overview

Landuse planning in the Netherlands has a long and standing tradition. Without going into details, and without going back as far as the late 19-th century or even before, one might say that governmental involvement, by introducing a general law on land development, started in 1924. As of that time there is a legally sanctioned mechanism to reorganize, reparcel and reallocate farmland for the purpose of strengthening the economy by upgrading the conditions under which foodstuff and fibers are produced. A national Central Committee is established to guide this process. In 1935 a Government Service is created and in 1938 a new land development law is introduced, expanding the legal instruments for land development.

After the war of 1940-1945, experience with the redevelopment of war-damaged, inundated land, leads to a further increase in activities within land-development schemes. These lead to some emphasis on landscaping, extending the objectives somewhat further than those purely aimed at agricultural development. In 1954, for the third time, a new law on land-development passes. As of that time, the optimization of land is being executed on the basis of land*use*, rather than such as before on the basis of ownership. The basic reason behind this is that, in the Netherlands, land hold on lease, is very common.

Five-year (land-development) planning is introduced in 1958 and budgets for periods of three year in a row are allocated. A boom in land-development occurs and much attention is given to the improvement of soil and waterconditions, and to that of the allocation of landuse through reallocation. In farm economic terms, a general and massive exchange of labor for capital takes place, with a severe drop in labor-intensity and a drastic increase of productivity per labor-unit and per hectare.

In the 70's the voting-system within the procedures for land-development, changes. In addition to landowners who already have the right to vote, tenant-farmers now see similar rights. In 1977 two special land-development laws are introduced for two specific areas. One for Midden-Delfland in the urbanized west of the country, and one for the peatland area of Oost-Groningen and Drente, in the northern part of the country.
In the 70's the public becomes increasingly aware of the decrease in size of natural areas and the qualities these represent, leading to governmental subsidies for nature protection. One may notice, that this occurs amidst (the continuous) cry-out for expansion of farmland per farmer. For a detailed and regional description of the dynamics, see Hetsen and Hidding (1991).
In 1985, the present (general) law on land-development passes the "house of commons", officially extending the development objectives to a much wider spectrum of landuses than merely those attuned to the agricultural activities within the rural areas.

A similar account of the country can be given when is looked at the development of the physical planning laws, which at first were primarily attuned to the 'organization' of urban areas. It started out in 1901 with a law providing rules for coordinating local governments for being able to cope with existing unhealthy *situations* within the city boundaries. In 1921 this law expanded to also deal with city *territory*.
In 1931 the law expanded even further, making built-up areas in rural regions possible. It lasted until 1941 before a National Service for the creation of a national plan was established.
In 1965 a general law on Physical Planning was passed, introducing a three-tier planning organization with local, provincial and national levels. As of that period, local governments and provincial governments make physical plans within the areas of their jurisdiction.
As of 1985, land-development activities fall under the realm of the physical plans. It then is officially stated and affirmed by law, that such activities have to be "in accordance with the functions attached to them by the physical planning".

In the Netherlands, there is this intertwining of physical planning and land development (see also figure 2-1), in which several social territories are involved. This ranges from individuals (farmers, tenants and other users of land) to

local governments, provincial and state. A balance in power, that is, in responsibility and social rights, has to be found; see also the interpretation as expressed in figure 2-7. Obviously, many interests are at stake.
As history shows, land-development has been engaged in seeking fulfillment of goals set for a number of sector-interests, starting out with those for agricultural production and extending itself towards a more multi-purpose instrument and activity. The weaving of such becomes increasingly intricate as more and more parties and types of landuses get involved, each with their requirements in terms of (different) soil and waterconditions and spatial needs; see fig.2-5.

Attaching much importance to landuse planning for reaching societal benefits, for many years now there has been experience with governmental guidance of land improvement. Not only have several related laws seen the daylight, and have many government services with tasks for plan development and implementation been established, but also and for many years now, public money has been spent accordingly. The activity has increasingly become an affair of multiple landuse planning, though most of the organization is still being run by the Ministry of Agriculture (, Nature Protection and Fisheries).
It presently has become a public debate whether it is wise to have the responsibility attached to such a multiple-landuse planning, within the hands of a sector Ministry. Some plea for more autonomy on the lower planning levels, for example the provincial levels. Some fervently plea for a more market-oriented approach, that is, for a halt to spending public money. Others, vigorously defend the need to continue incorporating public responsibility on the national level.

### 2.5.2. Landuse plan design-procedures

Passing by how initiatives are taken towards the land-development of areas within the Netherlands, it can be stated that the beginning of the design of the landuse plan starts off with research into the expressed problems. This is state-level initiated and executed, and presently results in the making of four sector-notes; one for the sector agriculture, one for the sector nature, one for the sector landscape and one for the sector recreation. In discussion is whether there should be one for the sector infrastructure. One might add that the number of necessary notes for which one might plea, can easily be expanded, especially in cases with multiple landuse. For example, one might think of a

note concerning the use of energy, or of one on the flux of chemicals, toxins, waste materials, and the like.
This part of the plan design-procedure is followed by the conception of several plan proposals, for which, for the various sector-interests identified, research has had to supply data. Primarily sector-oriented impact analysis of the plans conceived then takes place, skimming these for the final plan.
Obviously budgetary constraints, set by politics, play an important part in the conception of the series of possible designs. As far as the analysis itself is concerned, it has to be stated that inter-sectoral impact analysis has still to be developed into stages more profound, but at least some interchange of information within this phase of the planning takes place. The (few) plans in the race are adapted accordingly, and a final one, presumably the best, is chosen. See figure 2-12 for an overview of the present procedure.

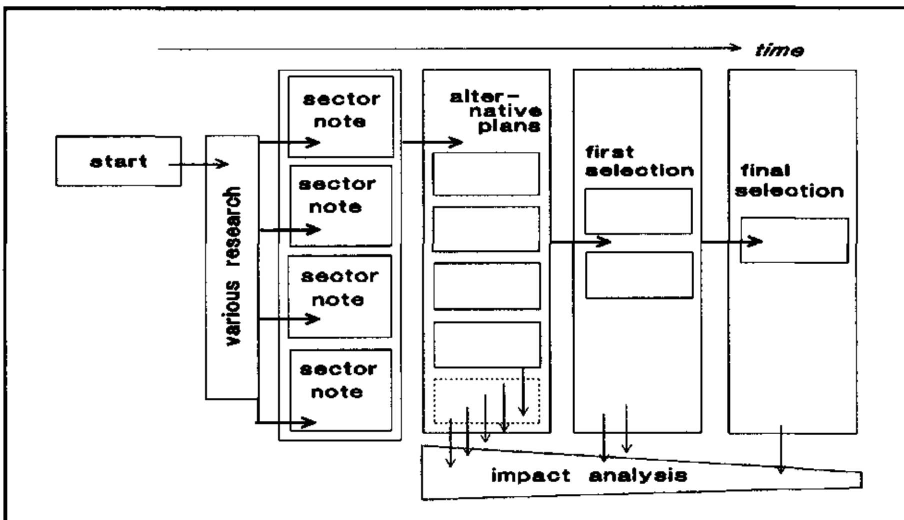



Figure 2-12. An overview of the plan-design procedure for land development in the Netherlands. (source: Oosterveld 1991, adapted)

At this point in the procedure, a voting on levels lower than that of the state, takes place. Where most obviously multi-interests are at stake, the ballot takes place on the intermediate, that is, the provincial level. In a situation with a majority of agriculture oriented goals, this voting (on a take-it-on-leave-it basis) takes place on the individual level of parties concerned. Where a majority in votes leads (either on hectare-basis or on number of votes), all parties concerned are confronted with the outcome. By (land-development) law, there is individual commitment to the public response.

### 2.5.3 Comments

As the example of the Netherlands shows, and no doubt a similar evolution occurs within a number of countries elsewhere, the planning of landuse involves more than such for just one landuse and is more than just a personal exertion. (See for example Brouwer, Thomas and Chadwick, 1991).
The planning of landuse is an involvement of individuals within society, with objectives of achieving higher standards of welfare and well-being by means (among others) of steering nature and creating conditions favorable for entrepreneurship and living.

One of the basic hurdles to take within landuse planning is the perceiving of and the setting of the goals to pursue. Once these objectives have been set, a conversion one way or the other, can take place to determine strategies. Most often these strategies are determined by problem reduction. The subsequent attainment of sub-goals leads (landuse) planners and parties concerned to the attainment of the main goals.
Within mono-functional landuse planning, the problems attached to the singular landuse might be fairly easily conceived, and with it the goals and strategies to overcome these problems and achieve the goals set. With multi-functional landuse planning, account has to be given of the inter-relationships between the landuses; and landuse optimization does not necessarily mean reaching out for the sectoral optimums. In fact, before even reaching out towards strategies levelling problems, there is a need for a conceptual space, one in which the various landuses relate to each other in a logic, world-true sense. Only then the problem can be truthfully seen in its multi-dimensional context, and only then means perceived to overcome the problem-distance.
The difficulty in creating a good internal representation of the problem not only depends on the number of landuses involved, but also on the fact man is not dealing with something static, but with something dynamic. We are dealing with processes in space and in time, obscuring the states and the inter-relationships of entities involved. What is needed, are spectacles to look with from a more global level rather than from a local, and from a more eternal level

rather than from a singular moment in time.
A third factor obscuring our perception, is caused by an attitude (still often encountered) to look upon the world as something separable from ourselves, as if there were no natural constraints for man and mankind, other than perhaps our own personal and societal capacities. A more organic view is needed in which man is part of the complex, in which he is actor and object at the same time.

The question at hand is, whether landuse planning can be attuned to the concepts expressed above. Not only is there a need for a better understanding of the environment in which man lives and of which he is part himself, also new design methodologies are necessary to deal with the interrelated multi-landuse objectives.
With § 2.3 it has been tried to present a concept in which the dynamic properties of the environment can be understood. The contours of a methodology which might possibly serve to overcome the problem-distance is given in § 2.4. Chapters 3, 4 and 5 in this study, are examples of new tools, useful within such a landuse planning setting.

## 2.6 SUMMARY AND CONCLUSIONS.

Land, the landuse planning object, is interpreted as an interrelated set of non-biotic, biotic and anthropogenic complexes.
Human possibilities for steering processes within these fields of interest are limited. Chances for steering however, lie within the use of the concept that the interrelated complex has cybernetic qualities.
The complexity of the interrelationships creates shortages in knowledge concerning processes and the conditions under which they occur. This complexity causes uncertainties about the effect of landuse proposals. It also causes a need for a better understanding of causes and effects.
Landuse planning is an activity consisting of physical planning, land development and land management, involving individual and collective thinking, directed at the physical and social organization of land. The ultimate goal is sustainable development.
A combined effort of monitoring and modelling creates possibilities for estimating the effects of human action, if use is made of procedures allowing

sensitivity analysis and feedback. This combined effort, when followed, can ensure finding landuse plan-proposals worthy of implementation.

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## 3. AKCI -- AUTOMATED MAPPING FOR C.I. DATA

### 3.1 INTRODUCTION

In the Netherlands a systematic monitoring of land-development areas has taken place since the 1960's by means of a technique known as the "cultuurtechnische inventarisatie", C.I. (van Wijk, Linthorst,1977). The resulting data-files contain some 75 attributes by which agriculture holdings within the reconstruction areas are described. These data can be characterized as being either socio-economic or topographic information.
Up to now, such data-files mainly have been used as a source for alphanumeric information for the land-development planning process. Little attention has been given to the use of such data-files as input for mapping, particularly mapping for analysis of the development areas. At first, the collected data were fairly straightforwardly presented in book-form (Bijkerk, Linthorst,1969), while later this was succeeded by output of computer programs creating several thematic tables of information. In the seventies, programs for more tailored and interactive tabular output evolved (Jurgens,1979,1982; Voet,1981a,1981b; Vaartjes,1982; FOCUS,1986).
With the presently developed computerprogram AKCI, there is today a program for an interactive use of C.I. data-files, producing thematic maps of the land-development areas described by the data-files. The acronym AKCI stands for Automatic Cartography from the C.I., in Dutch: *Automatische Kartografie vanuit de C.I.*

The following paragraphs contain an outline of the C.I. data-files. Included are their use and present shortcomings as well as the adaptations made for use of the interactive cartography program.

### 3.2 C.I. DATA-FILES AND THEIR RELEVANCE FOR LANDUSE PLANNING

The use and usefulness of C.I. data-files depend on the type of data stored in the data-files and to some extent on the ease of extracting data from these files. At least three data-categories are relevant for landuse planners:

1) alpha-numeric data, for example:
   - the size of agriculture holdings
   - the number of farmers related to subarea S
   - the number of landuse units with a certain condition
2) topographic data, for example:
   - the location of the farmhouse of a certain holding H
   - the location of a certain landuse unit U
   - the size of a landuse unit
3) topological data, for example:
   - the land in use by farmer F is located ...
   - the land on location $L_{xy}$ is used by ...
   - the land 'next door' is ....

**Information categories**

For recording purposes, each agriculture holding above a certain size[1] is described by means of two categories of information, one being the socio-economic entity known as agriculture enterprise, the other being the topographic entity known as '*kavel*'[2]. Non-farm landuses and their whereabouts are not registered, nor is ownership. Attributes within these two categories can be grouped as shown in Table 3-1. For a complete list, see Appendix 1.

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1

Holdings with 10 SBE or more are taken into account.
SBE, *standaard bedrijfseenheid*, is a farm-economic measure to appraise production capacity on the basis of number and type of animals, type of crops and area involved.

2

Within the Netherlands one distinguishes *'perceel', 'kavel', 'bedrijfskavel'* and *'bedrijf'*.
***Perceel*** is the smallest topographic landuse unit, used by an agriculture holding. The unit can serve one crop type at a time only; otherwise more units have to be distinguished.
A ***kavel*** is a conglomeration of percelen in use by the same user; these *kavels* are pieces of land not divided by roads, waterways and/or railroads.
A ***bedrijfskavel*** is a conglomeration of *kavels* in use by the same user; the land may be split by roads, waterways and railroads.
***Bedrijf*** is the word for farming enterprise. It may contain a number of *bedrijfskavels*.
When referring to ***% veldbedrijfskavels*** one refers to the (percentage of) area taken in by all *bedrijfskavels* separated from the farmhouse; in general this refers to the (percentage of) area " lying further down the road". The remaining (percentage of) area is addressed to as ***% huisbedrijfskavel*** area.
See VEMCI (undated).

Any information stored on either *kavel* or the holding level can be matched to the other by means of unique user-codes. If for example, a certain user/ holding is known to belong in the category 'horticulture', all *kavels* belonging to his holding can be traced by means of the user-code.

Table 3-1. Categories of C.I. entities and attributes.

| category | attribute-type |
|---|---|
| agr.holding | - user-code |
| | - holding-data |
| | - topographic data of farmhouse location |
| *kavel* | - user-code |
| | - landuse data |
| | - topographic data of *kavels* |

Table 3-2. AKCI holding-categories.

| category | description | |
|---|---|---|
| 1. | arable farming, | no part-timing |
| 2. | dairy farming, | no part-timing |
| 3. | horticulture, | no part-timing |
| 4. | specialist, | no part-timing |
| 5. | mixed farming, | no part-timing |
| 6. | part-time farming, | arable farming |
| 7. | part-time farming, | dairy farming |
| 8. | part-time farming, | horticulture |
| 9. | part-time farming, | specialist |
| 10. | part-time farming, | mixed farming |

**Holdings**

The attribute 'holding-type' differentiates between some 170 types of agriculture holdings. On initiation of the AKCI program, some new attributes are created, among which is one for the holding-category, making a functional distinction between 10 types of enterprises. See Table 3-2 for the additional categories[3] used within AKCI, including a distinction based on farm production

3

The categories are based on SBE-values within the various sub-holding types distinguished within the Dutch statistical surveys. Usually if 60% (or more) of the total SBE of a holding is found within a sub-type, the agriculture holding is given that sub-type.

type and the presence of part-timing[4]. See figure 3-1 for the general procedure with types of input and output.

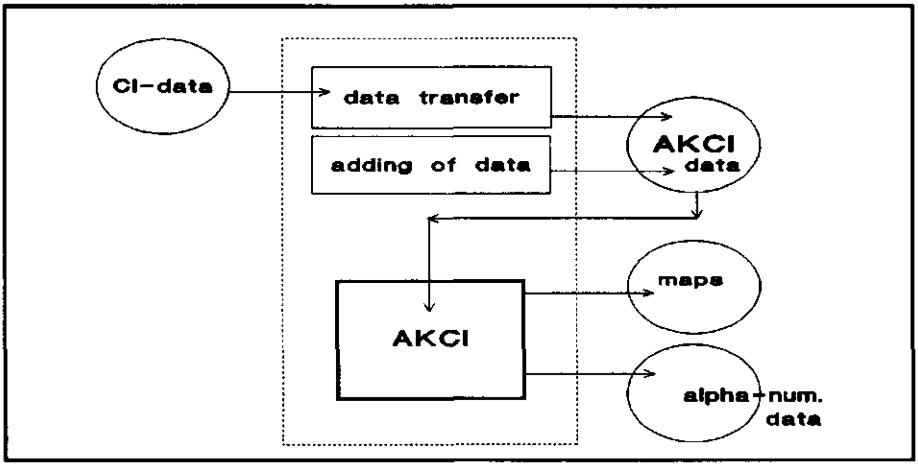


Figure 3-1. AKCI in an overview with input and output

**Landuse data.**

Since landuse planning is planning for new situations, knowledge and an understanding of the locations and types of landuse are necessary before one can envision new road-layouts and improvements of accessibility, new forms and sizes of land units, and the reallocation of landuse.

From a planning point of view, agriculture production processes are to be known and evaluated. Alternatives have to be weighted one against the other. Financial-economic appraisals of farm operations have to be made, with benefits weighted against investments and daily costs. Also to be known are data on farm management respective the type of agriculture holding, and data on prices of output and those of input.

Within land-development projects, C.I. data-files are used as information source for such appraisals, in line with the Dutch Impact Analysis Procedure

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4 In the Netherlands, a farmer spending 50% (or more) of the working hours available within the farming enterprise, is taken as a full-time farmer. A part-time farmer is one who spends less.

called HELP[5]. See for an early example Jurgens, van Rheenen and Meeuwse (1980).

For evaluation purposes a main distinction is made between farm management operations within the farm buildings, opposite to those on the field. Within the latter category a main sub-distinction is necessary between work around the farmhouse and work done on fields not directly connected to the main farm buildings. See Landinrichtingsdienst (1983, 1984) and Bosma (1986) for more information on the HELP-method.

Availability of agricultural data and possibilities for extracting such data from the data-files, are shown in Table 3-3.

Table 3-3. Economic data needed for HELP and the possibility of extracting such from a C.I. data-file.

| variable | attribute known within the C.I. | possibility of extracting |
|---|---|---|
| type of agr. holding | + | + |
| 60% -criterion | - | + |
| 80% -criterion | - | + |
| 100% -criterion | - | + |
| % *veldbedrijfskavels* | - | + |
| % *huisbedrijfskavels* | - | + |
| mechanization-level | - | - |
| amount of contractor work | - | - |
| size of smallest production unit | - indications only | - dito |
| travel distances to production units | - indications only | - dito |
| % waterlogging/shortage depression | - | - |
| soil type | - | - |
| gross/net production level | - | - |

Table 3-3 indicates that a number of variables required for HELP are not readily available within the C.I. data-files, but they are obtainable. On initiation of AKCI, data within the C.I. data-files are transported into a AKCI data-

5 In the Netherlands an evaluation system HELP was developed and introduced in the mid-eighties, in which the expected results of plans are measured against those expected in an autonomously developed situation. The method is primarily operational for agriculture, although other landuses are taken into account as well. For more detail on HELP, see Bosma (1986).

base to which are added the attributes and values to be known, as far as they can be derived by manipulation of the basic data within the C.I. data-files. See Table 3-4.

Table 3-4. Attributes for which values are given on initiation of AKCI, based on data within C.I. data-files.

| |
|---|
| aggregate type of agriculture holding |
| number of *bedrijfskavels* per farm |
| number of *kavels* per farm |
| *% huisbedrijfskavel area* per farm |
| length/width value per *kavel* |
| weighted travel distance between *kavel* and farm house |

In respect to land-development planning such criteria as the 60% criterion[6], and travel distances to the production units in the fields, are important. Unfortunately, not all information needed is either readily available in the data-files, or extractable, since the items have not been investigated.

With the data in the C.I. data-files, it is possible to estimate farm management activities for various types of agriculture holdings. Using data on sizes of land units, and travel distances between them, a fair indication of required labor can be derived by means of a program called IMAG56. However, some data on mechanization level is required as well (IMAG,1982; Werken,undated; Roetert Steenbruggen,1986).

Table 3-5 shows which management categories are monitored for C.I. data-filing. Some data on levels for which there is no recording, can be extracted by means of aggregation operations, but only if relevant data on a lower entity level exist. If, for example, the size of a farm-unit would not have been recorded, the number of hectares could be calculated by adding up *kavel*-sizes of the relevant *kavel*-units, but of course only if sizes for these *kavels* were

6

The variable 60% (,80% or 100%)-criterion refers to the percentage of the land development area belonging to agriculture holdings for which at least 60 (,80 or 100) percent of the total area of the respective acreages is near the main farm buildings.

recorded.

Table 3-5. Management categories and C.I. monitoring

| management category | C.I. monitoring |
|---|---|
| development area | - |
| agriculture holding | + |
| area near main farm buildings (*huisbedrijfskavel*) | - |
| area remote from farm buildings (*veldbedrijfskavel*) | - |
| *kavel* | + |
| *perceel* | - |

Figure 3-2 shows a hierarchy of management units identified within land-development areas; from bottom up: *perceel, kavel, bedrijfskavel*, agriculture holding.

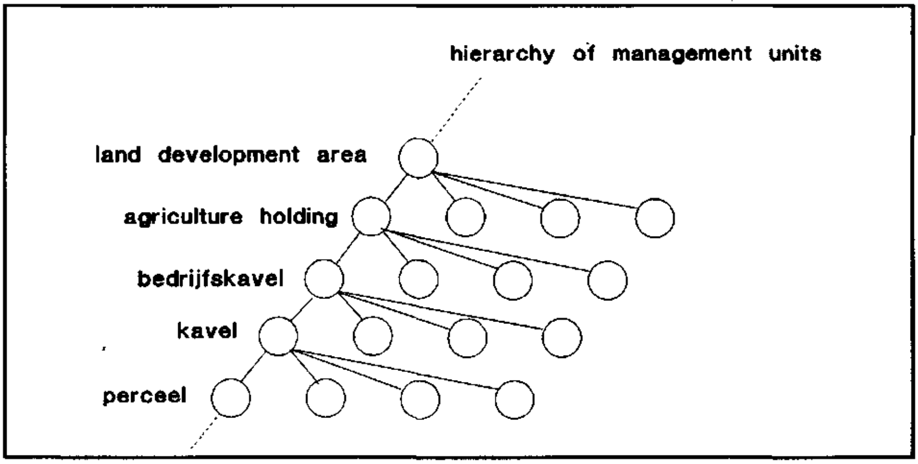


Figure 3-2. The hierarchy of management units

**Landuse analysis**

Figure 3-3 shows a detail-map of an area called Noorderpark, showing *kavels* colored as a function of number of *bedrijfskavels/bedrijf.* The larger the number, the less favorable the farming situation.

Figure 3-4 shows *huisbedrijfskavels* colored as a function of the area-percentage they occupy within the farming enterprise. Those with less than 60% are not very favorable and belong to enterprises in need of some change.

Figure 3-5 shows the distance the *kavels* have relative to the location of the farm-buildings. The larger the distance, the less favorable the situation.
Figure 3-6 shows the tabular feature of AKCI, allowing alpha-numeric output of *kavels* (or enterprises) to be shown next to the map-output.

## 3.3 SOME OPERATIONAL ASPECTS

**Interactive use of AKCI**
AKCI has been created as a real interactive color-graphic, vector-oriented computer program for use for landuse planners. Use is fully menu-driven. For AKCI no knowledge of system query language (SQL) is therefore needed.

**Thematic mapping**
With the program AKCI it is possible to show topological[7] information through automated mapping. By coloring the location of entities based on attribute values, thematic maps are created. Zoom-functions allow in-depth mapping of any sub-region within the land-development area covered by the data-base. Roads, farm houses and land units colored according to legend are shown. See for examples the figures 3-3, 3-4, 3-5.
AKCI allows certain boolean matches of attributes[8], making it possible to create thematic maps.

---

7

From a map-point of view reference is made to the relationships between points, lines and areas. From a user point of view, the relevance lies in the relationships between sub-areas, farmbuildings, users, landuse and other qualifications as stored as attributes within the database.

8

Reference is made to the making of sets of elements (that is, attributes of the entities within the data-files) with attribute values within certain ranges. These ranges can be given interactively. Only those elements within the union of the sets can be displayed. Example:
One wishes to make a thematic map, showing data of dairy-farmers, but only the *veldkavels* and these colored according to some range of distances on the basis of their respective distances *kavel*--farmhouse.
This requires finding the union of the set of dairy farmers, the set of *veldkavels* and the set distances.

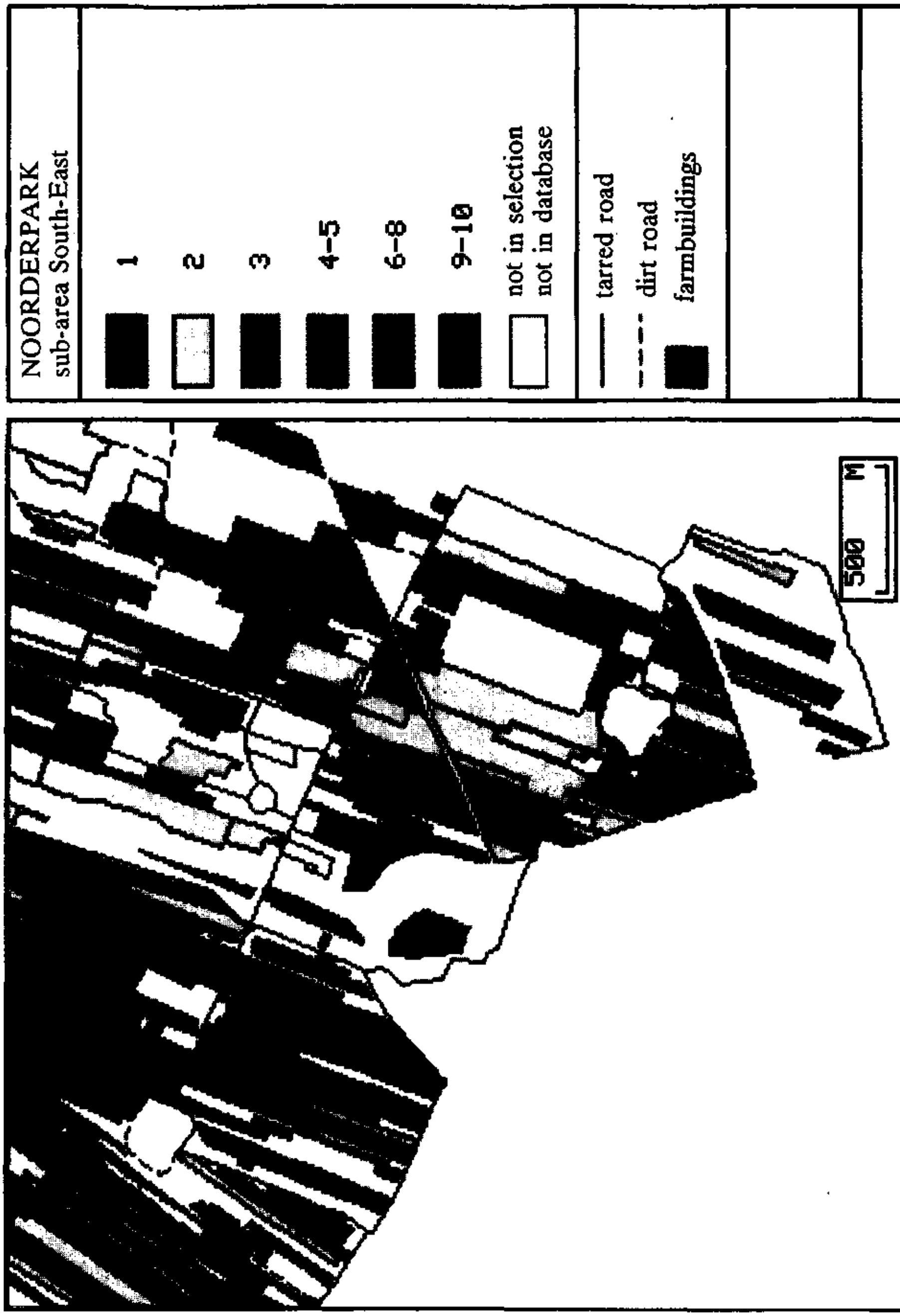


Figure 3-3. Output example AKCI. Theme: number of *bedrijfskavels/bedrijf*.

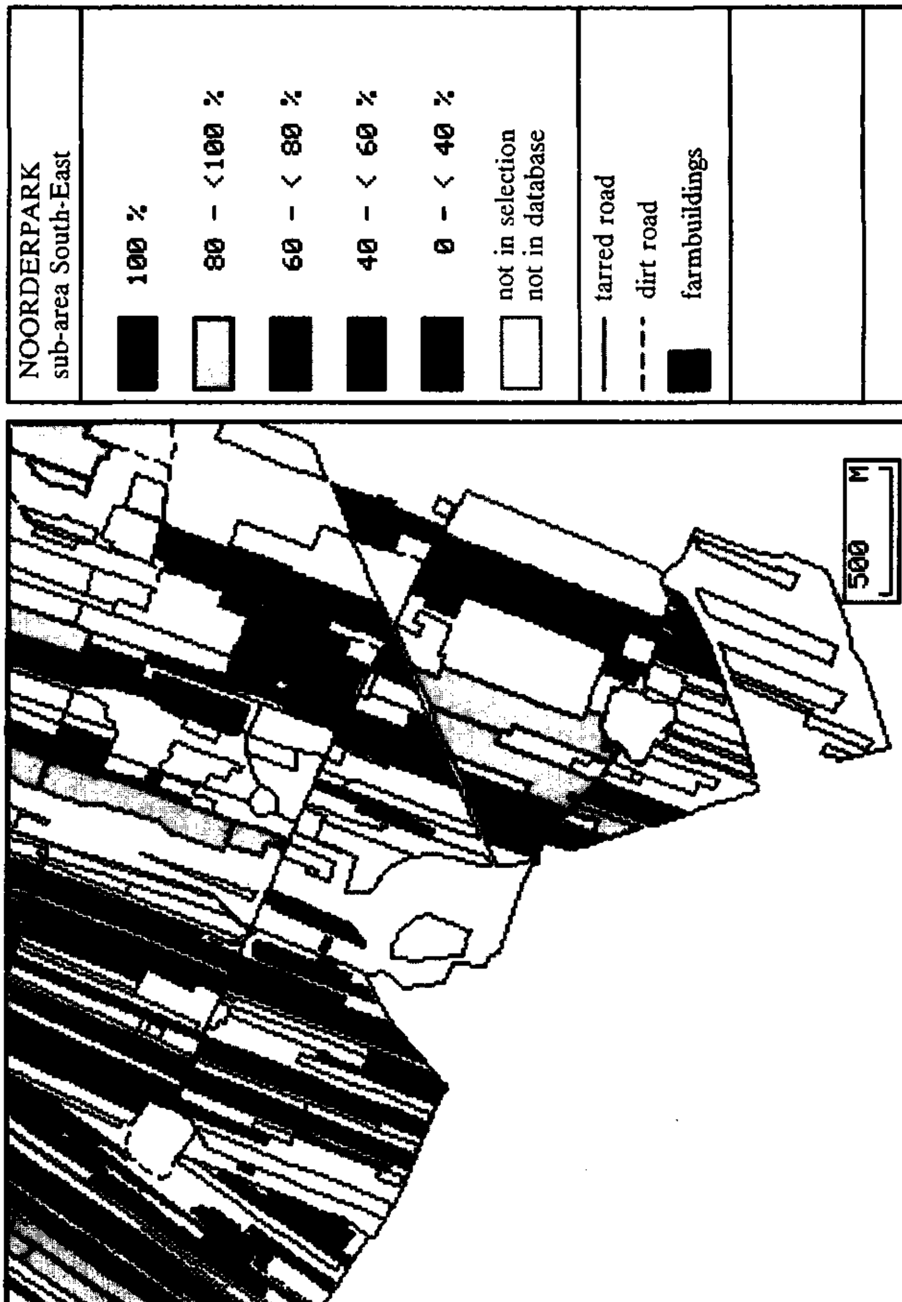


Figure 3-4. Output example AKCI. Theme: *huisbedrijfskavels* colored for % of *huisbedrijfskavel.*

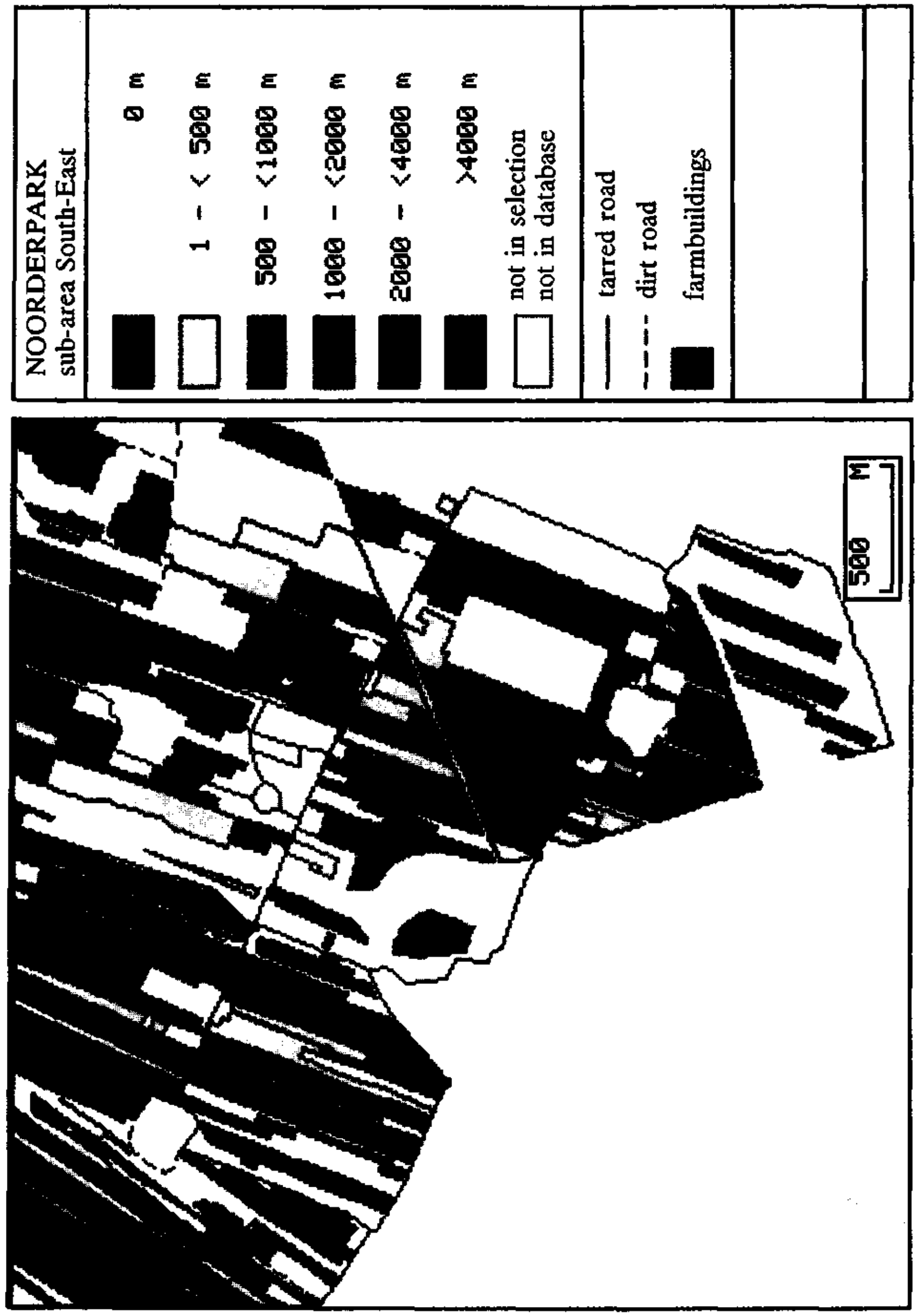


Figure 3-5. Output example AKCI. Theme: real distances (by road) of *kavels* to farmbuildings.

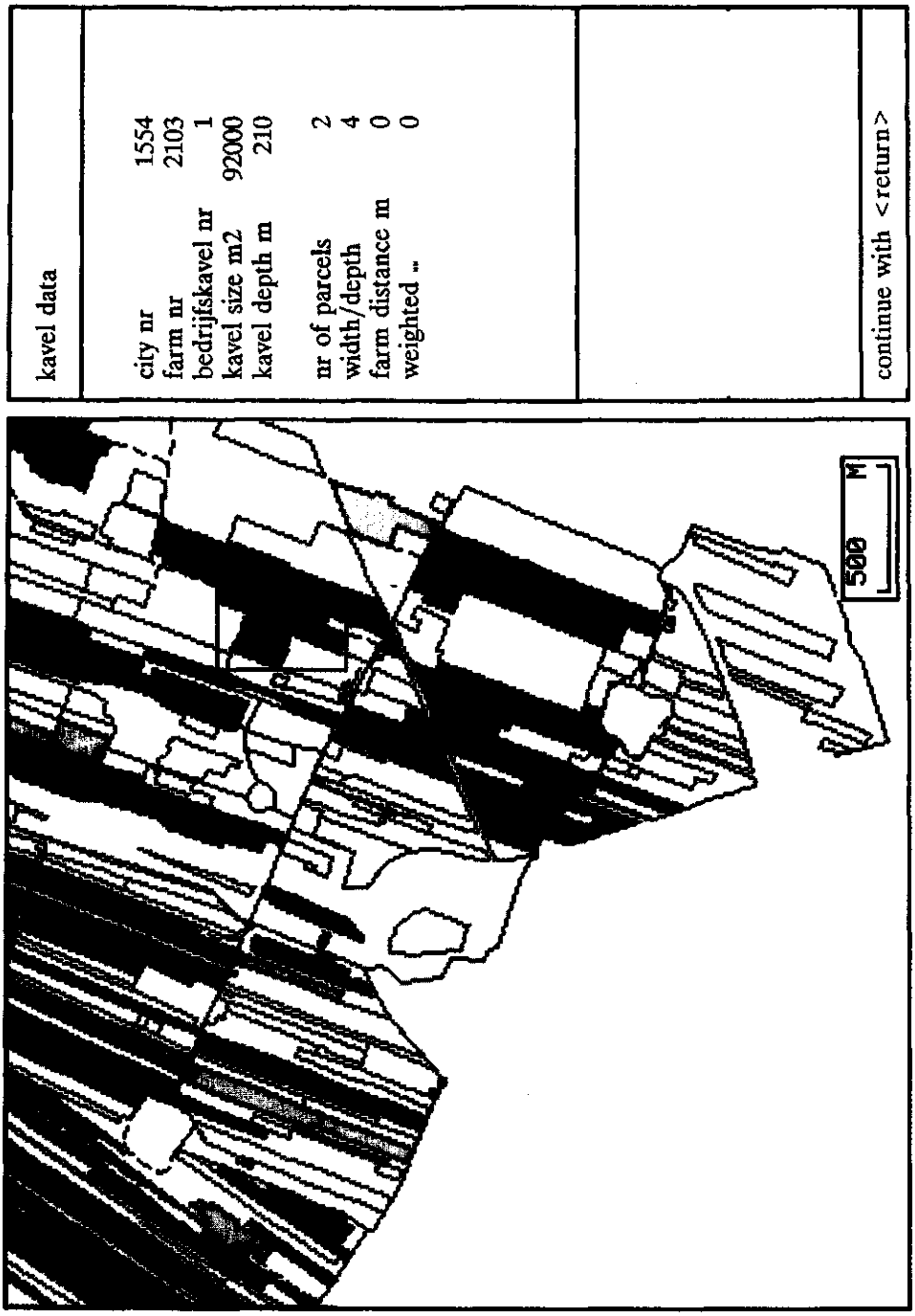


Figure 3-6. Output example AKCI. Mapping output with numeric data of a *kavel*.

**Tabular output**

In addition to automated mapping, provisions have been made to make it possible to see alpha-numeric data. By pinpointing the screen's haircross-cursor on either a *kavel* or farm building, alpha-numeric data of the object can be projected next to the created map (Kuijpers, 1989). See figure 3-6 for an example of resulting output.

In addition to this type of output, file-output with data on the attributes of the selections can be made, allowing further investigation.

**Attributes**

The AKCI data-base presently is filled with data found within C.I. data-files, to which are added some relevant attributes. The file organization is such that the addition of attributes from sources other than the C.I. data-files is possible, extending its use into a field not strictly confined to C.I. data-files.

**Privacy aspects**

The C.I. data-files contain socio-economic information on agriculture holdings, making these files privacy sensitive. AKCI has been designed so that, on initiation and by choice, attributes can be shielded from use. Whenever necessary, semi-different AKCI-programs[9] can thus be presented, without having to change the data-set or the program-source.

**Hardware/software**

AKCI has been written in FORTRAN-77 using VAX/VMS (Thewessen, 1987; Kuijpers, 1989). It uses the GKS-UNIRAS toolbox of European Software Contractors. AKCI operates on graphic terminals of the TEK42xx type.

## 3.4 SUMMARY AND CONCLUSIONS

"Cultuurtechnische Inventarisatie" (C.I.) data-files, in use by the Dutch Government Service for Land and Water Use are useful, but limited, information sources for planning in areas under redevelopment.

9

Reference is made to so-called executables or EXE-files as a result of the compilation of the program-source and its linking.

The C.I. data-files are (presently) strictly used for recording socio-economic data of agriculture holdings to which are added topographic data on landuse units. The files contain few data on farm management. They do not contain information on soil and water conditions, nor on biotic data. The use of C.I. data-files is also limited because the files contain data covering 'one snapshot in time' only, rather than a series of observations.

Although the use of C.I. data-files for purposes of economic evaluation is limited, the data sets do contain worthwhile socio-economic and topographic information and are useful for landuse planners.

An interactive color-graphic, vector-oriented computer program which uses the C.I. data-files has been created. With this program, called AKCI, automated mapping and a visual investigation of development areas, as described by the attributes within the data-bases, is possible.

The AKCI data-files have been created so that data other than those within a C.I. data-set, can be stored, thus extending the use of the program beyond the strict confinement of the C.I.

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## 4. INTRANET --
## Planning tool for INTeractive Route Analysis in NETworks

### 4.1 INTRODUCTION

The rural road system is an object worthy of study because of its intermediate importance to all types of landuses. Although roads occupy space which perhaps could have been better allocated to other landuses, their main importance is derived from being a transport medium.

In the Netherlands, land-development projects have caused considerable changes in the existing rural road system, as can be seen in Table 4-1.

Table 4-1. Examples of changes in rural road systems within land-development projects in the Netherlands, period 1975-1990.

| Project | finalized | size area ha | km tar (1) | km tar (2) | km semi-tar (1) | km semi-tar (2) | km non-tar (1) | km non-tar (2) | km difference total |
|---|---|---|---|---|---|---|---|---|---|
| Koewacht | 1975 | 5220 | 90.5 | 125.6 | 6.5 | 0 | 97.3 | 4.2 | -51.5 |
| Vries | 1976 | 7050 | 58.5 | 152.6 | 7.4 | 0 | 158.0 | 28.5 | -42.9 |
| Steenw.Oost | 1977 | 2920 | 29.0 | 44.0 | 5.5 | 2.3 | 31.6 | 7.4 | -12.4 |
| Hattem Wezep | 1978 | 3060 | 31.0 | 54.0 | 14.0 | 0 | 25.0 | 0 | -16.0 |
| Uden | 1979 | 3670 | 52.0 | 102.0 | 0 | 0 | 180.0 | 17.0 | -113.0 |
| de Poel H.Z. | 1980 | 7040 | 145.0 | 177.0 | 59.4 | 17.0 | 52.4 | 3.7 | -59.1 |
| Bergen | 1981 | 7860 | 94.0 | 165.4 | 95. | 75.7 | 200.0 | 0 | -241.9 |
| OverBetuwe N. | 1982 | 4200 | 47.6 | 78.3 | 22.0 | 0 | 8.3 | 0 | 0.4 |
| Diever | 1983 | 3490 | 36.1 | 63.6 | 0 | 2.1 | 110.0 | 18.0 | -62.4 |
| Schaft | 1984 | 2230 | 27.5 | 39.4 | 0.6 | 1.6 | 83.3 | 27.6 | -42.8 |
| Bakel | 1985 | 7770 | 125.8 | 161.0 | 30.0 | 7.0 | 230.0 | 65.0 | -152.8 |
| De Marne | 1986 | 7620 | 86.0 | 110.0 | 8.0 | 5.0 | 18.0 | 2.0 | +5.0 |
| Overloon-M. | 1987 | 8140 | 87.0 | 133.2 | 4.0 | 7.1 | 300.0 | 70.3 | -180.4 |
| Oude Graaf | 1988 | 2850 | 63.7 | 75.0 | 5.5 | 7.1 | 82.2 | 19.2 | -50.1 |
| Rijk van Nijm.Z. | 1989 | 3880 | 72.3 | 93.3 | 42.7 | 14.5 | - | - | -7.2 |
| Borculo | 1990 | 4863 | 101.0 | 118.0 | - | - | 65.0 | 7.2 | -40.8 |

(1) before
(2) after
source: Government service for Land and Water Use.

Table 4-1 shows development projects in the Netherlands, of a size up to and over 7.500 ha. A large increase in tarred road length, due to an upgrading of dirt roads, can be seen. The total road length, however, has decreased substantially.

In order to adequately analyze the road infrastructure in the landuse planning process, it is necessary to answer the questions:

- can land-management be upgraded by upgrading the use[1] of the road system?
- can land-management be upgraded by changing the road intensity?
- can land (re)development be enhanced by changing the road system layout[2]?
- can analysis of the network serve solving problems, related to the (re)allocation and reallotment of landuses?

Within landuse planning road-use planning requires a focus on traffic analysis, with a strong emphasis on data collection and processing of data concerning traffic volume (e.g. Jaarsma,1984), accidents (e.g. Wegman, Mathijssen, Koornstra, 1989) and the appreciation of isolation as it affects accessibility to social services (e.g. Huigen,1986).
Within the field of operations research (O.R.), much attention is given to routing and scheduling as a means of reducing travelling costs and effecting timely pickups and deliveries (e.g. Bodin,1983). Thus, O.R. looks at road-systems from a vehicle movement and management point of view.

As one of the leading hypotheses in this study was formed, the idea that where road-network layout and road-construction are part of the landuse planning task, the planning for optimal movement must lead to better plan proposals.
Many landuse planning questions relate to travel. Distances and time involved are basic parameters in many studies. They ultimately aim at reducing travel and time involved, lowering cost prices, lowering energy needs, lowering labor consumption, lowering material costs, and the like.

The need to incorporate travel issues into landuse planning programs, has

1 Example: travel optimization.

2 Examples: change in spatial location of roads; making of new connections; removal of unnecessary roads.

resulted in the computer program called INTRANET, a program for an INTeractive analysis (and planning) of Routes in NETworks. From the O.R. point of view, INTRANET contributes for speed-enhancement in large networks due to:

- (possible) decomposition of the network into sub-networks and
- adapted shortest route calculation procedures.

While the landuse planner can use the program for general and in-depth analysis, its main features are the planning and calculation modules for optimal routing, for allocation and for vehicle/labor scheduling. Editing modules allow network changes for the creation and study of plan alternatives.
The developed program is color-graphic, vector-oriented and fully menu-driven.

**modelling INTRANET**
In-depth analysis of road infrastructures requires data on each part of the road system. Fast algorithms for determining distances and routes are required, since much data is involved.
Special attention has to be given to data storage space, since large amounts of data are involved. This is particularly the case when planning is done in an interactive setting with feedback of results.

For purposes of modelling, road systems can be interpreted as networks[3], that is, sets of nodes and arcs, with the nodes representing:

---

3

Formally, a network may be defined as having:

- a set N, containing elements called nodes
- a set E, containing unordered pairs of nodes, denoting the connections (links or arcs) between nodes.

Of landuse planning interest are those sets N, in which each node, by means of the set E, has a path to any other node within set N.
Usually, a distinction is made between directed and non-directed networks. The former refers to a set E, in which the sequence given to pairs (i,j) indicates the direction of flow within the arc.
In non-directed networks, the sequence of nodes in set E does not indicate a restricted direction of flow. In landuse planning dealing with rural areas, most often the latter type is the case.
A path in a network is a sequence of connected arcs, such that in the alternation of nodes and links no node is repeated.

- road entrances to (agriculture or other) holdings,
- road entrances to landuse units
- crossings/junctions of roads
- transitions within roads (road quality, topographic orientation).

Any place of interest -- from the viewpoint of any type of landuse -- can be modelled as node in a network. Any transit medium (not only roads but also waterways, railways and many others) can be modelled as a network consisting of an interrelated set of nodes and arcs. Thus, the scope of this approach surpasses that of landuse planning as an independent exercise.

INTRANET should have features, making it possible:

a) to cope with large networks of nodes and arcs and

b) for planners to get (model-)answers within reasonable CPU-time[4].

In theory, the computational burden involved in the calculation of the shortest distance in a network, is excessive in cases with many nodes. In general, it is necessary to perform $O(N^3)$ calculations[5], with N being the number of nodes involved.

This approach leads to costly computer work, meaning that this type of research can go undone. If, for instance, 10.000 nodes are involved, the number of calculations for determining the shortest distance between all nodes, lies in the order of 1.000.000.000.000 calculations. Obviously, such calculations require substantial computing and storage capacity.

---

4 CPU-time refers to the time the central processing unit of a computer requires to control, interpret and execute the instructions.

5 With N nodes in the network, there are $N^2$ distances to be known.
The basic procedure for calculating shortest distances, is based on a method whereby a tentative shortest distance between two nodes is compared to a set of distances, as a result of travelling via an intermediate node. Since there are approximately N 'other' nodes, the calculation burden therefore is of the order (O) of $N^3$.

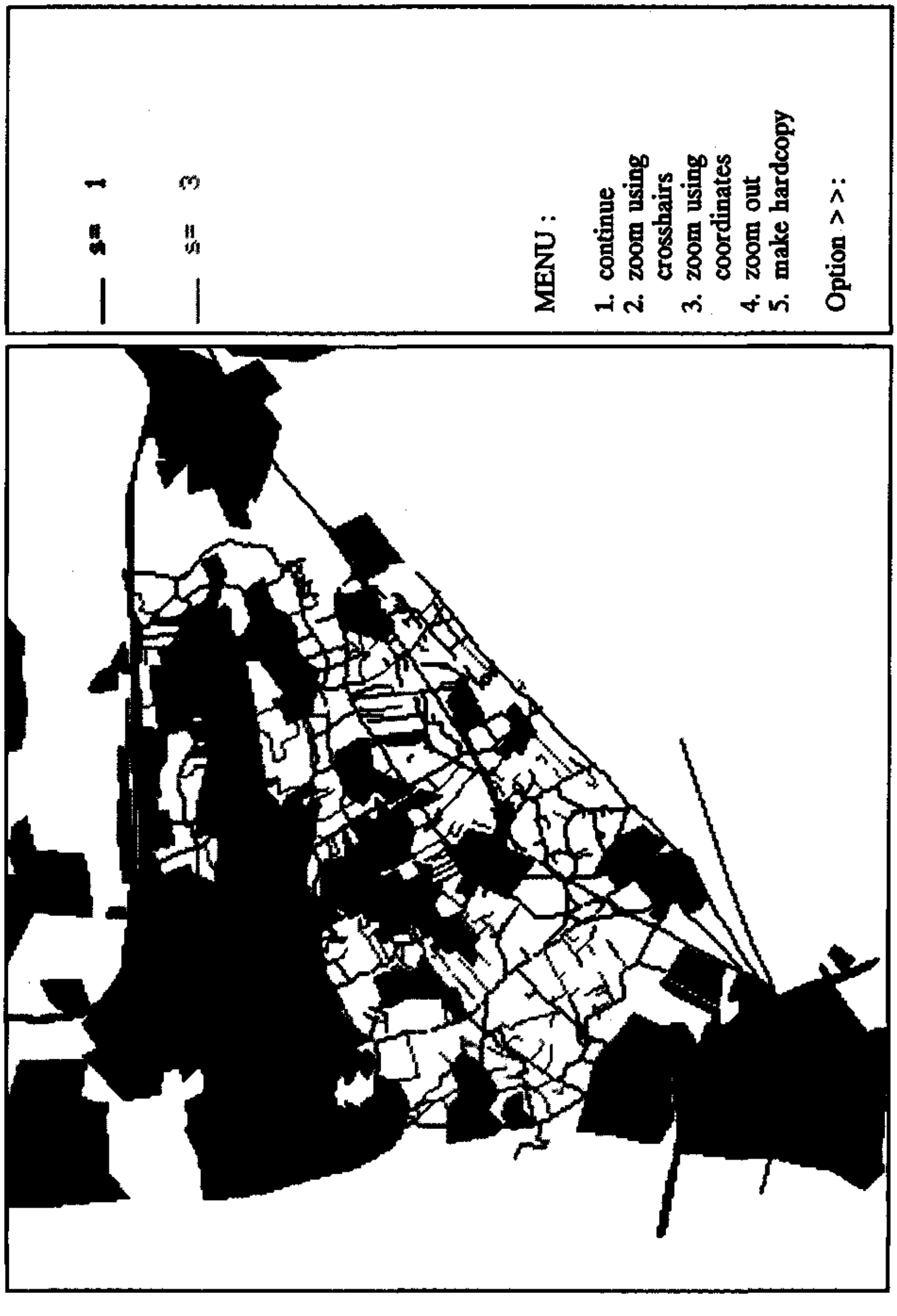



Figure 4-1. An example of an INTRANET-network with background display.

The INTRANET study has concentrated on finding an exact[6] algorithm to fit the desired interactive planning setting (see chapter 1).

INTRANET can handle large networks due to:
- the use of a method for network decomposition in conjunction with
- a reduction of nodes involved and
- the upgrading of an algorithm found best.

The program has been used successfully on data-sets of over 8000 nodes and 5000 arcs, and it has the following features:

1. display (that is, a mapping) of networks for visual interpretations
2. calculations of distances between any two nodes
3. display of the shortest route between any two nodes
4. accessibility calculations and display of results
5. route labor planning
6. graphic and alpha-numeric editing of input-data

Figure 4-1 shows a screendump of a display as produced by INTRANET, showing various road-qualities of the network, as well as some background data like built up area, woods and water within the area.
Figure 4-2, created with the AKCI (see chapter 3) is to be interpreted in alliance with figure 4-3, output of INTRANET, both showing the same subarea of a landdevelopment area called Ruinen.
The numbers in figure 4-3 are either entrances of landuse units in respect to the road-network, or points of network-transition[7], or junctions.

6 Heuristic algorithms, as opposed to exact algorithms, provide feasible or near-optimal solutions in a fairly fast way. They are often used in stead of algorithms leading to exact solution(s). The latter usually require considerable more CPU-time.

7 Examples: change in road-quality, change in road-orientation.

## 4.2 MAPPING

The mapping of networks is necessary for plan documentation and for visual information for planners and decision makers while planning.
From a display point of view, INTRANET presently allows:

- display of overviews, or
- detailed mapping for any subregion,
- thematic mapping as far as impedance values[8] are concerned;
- the use of background files, allowing overlays of the network data and INTRANET-output with (INTRANET-formatted)[9] data-files covering data of, for example, other objects of interest like railroads, waterways, urban and sub-urban areas, woodlands, lakes, and the like.

Figures 4-1 and 4-3 illustrate examples of INTRANET output.

## 4.3 DISTANCES

Within landuse planning projects at least three types of distances are to be distinguished:

1) *Euclidean distance;*
   that is, the distance between two locations; the Euclidean value d(i,j) can be calculated from the (x,y) coordinates of the two locations i and j:

$$d(i,j) = [(x_j - x_i)^2 + (y_j - y_i)^2]^{1/2}$$

2) *travel distance;*
   that is, the shortest distance between two locations i and j, using the network as the medium through which to pass; thus, to be calculated:

---

8

Different quality-values attached to the links are used as impedance weight. If, for instance, a certain link has been given a weight 2, the length of the link is taken twice its Euclidean length.

9

Reference is made to files in point, line and plane-format accepted by INTRANET.

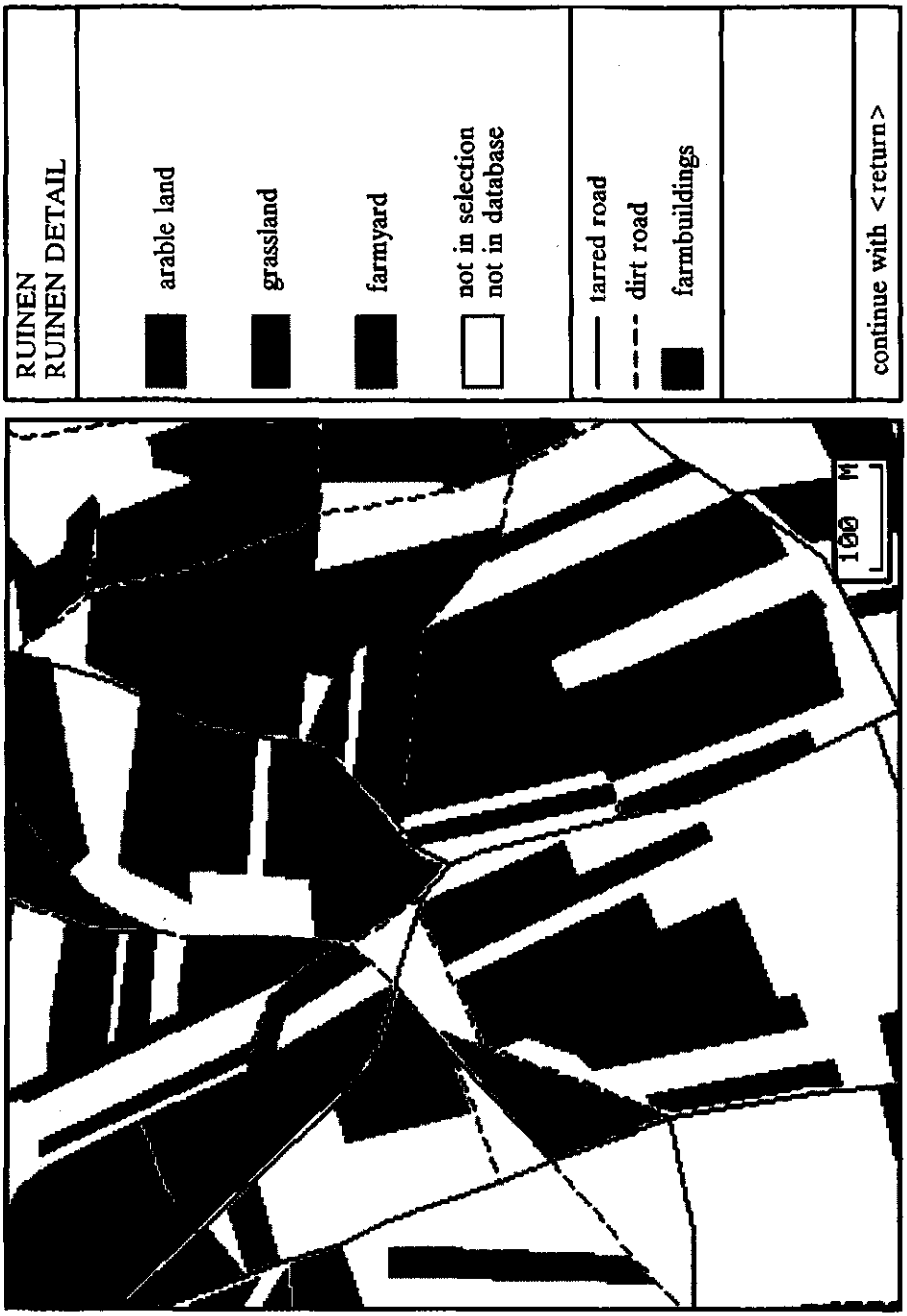



Figure 4-2. An example of AKCI-output; a detail-map of Ruinen-AREA.

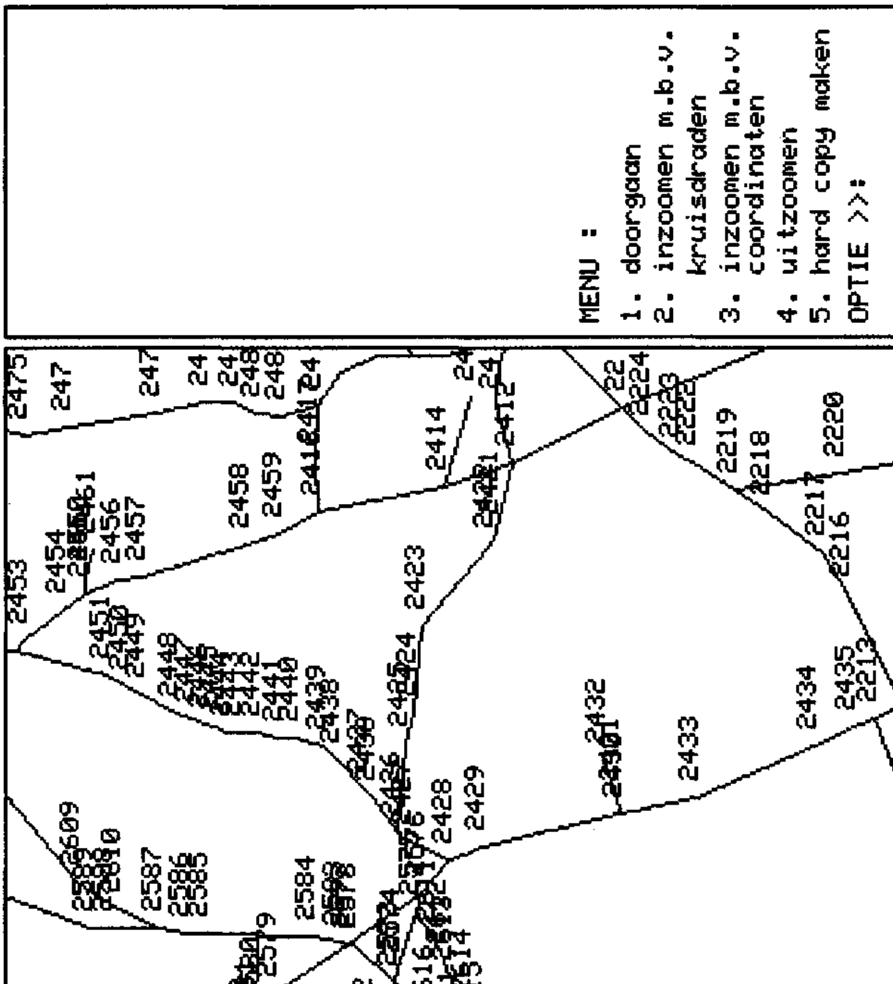



Figure 4-3. An example of INTRANET-output; a detail-map with node numbers of Ruinen-area.

$$\min \left\{ \sum_{r=1}^{n} \sum_{s=1}^{n} d(r,s) \right\}$$

3) *weighted distance;*
that is, distances similar to those of 2) but difficulties, such as those encountered while travelling from one location to the other due to different road-quality, are taken into consideration;
The calculation procedure is similar to one under 2), but each link has to be multiplied with its impedance value w(r,s) first; so, to be calculated:

$$\min \left\{ \sum_{r=1}^{n} \sum_{s=1}^{n} w(r,s).d(r,s) \right\}$$

Within INTRANET all calculations are done on the basis of type 3, thus requiring impedance values for every arc that is distinguished.
In case all roads are of equal importance, impedance values equalling 1 are to be used. It is up to the landuse planner to decide which impedance values are to be used. At present the use of integer-values in the range 1-9 is requested.

## 4.4 NETWORK NODE REDUCTION

In network computation CPU-time needed for the calculation of shortest distances can be expressed as a function of the number of nodes in the network. The more nodes involved, the larger the time needed to perform the calculation. From a theoretical and practical point of view the question has to be posed as to whether it is possible to reduce the number of nodes to be included in computations without affecting the result.

Within INTRANET a solution for this has been found through:
- reducing the total-network matrix to a network-matrix consisting of so-called significant nodes[10] only and by

10 In road-system terms, one might think of a reduced system, consisting of junctions only. See also figures 4-4 and 4-5. With respect to land-development

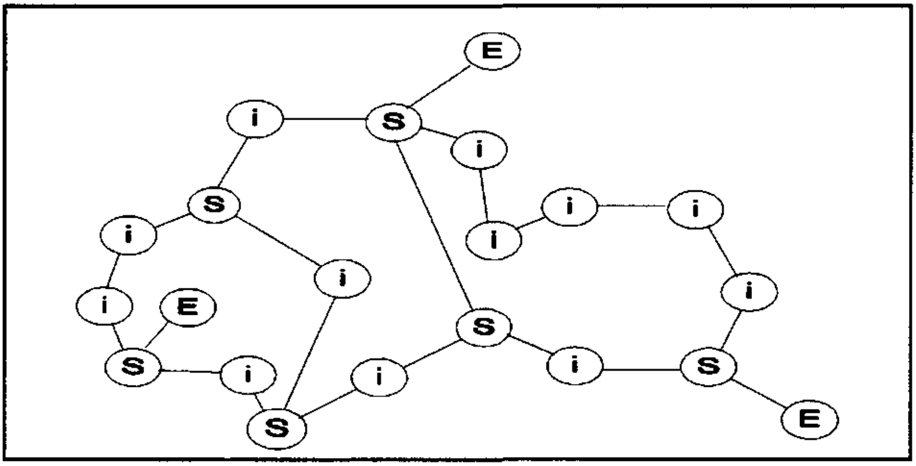
- applying shortest distance algorithms on these reduced networks only

Figure 4-4 shows a network configuration with three types of nodes which can be distinguished within networks:

a) the dead-end node, having only one arc attached
b) the intermediate node with two arcs, and
c) the significant node with more than two nodes.

These type c) are network-significant because the nodes of this type determine the spatial structure of the network.

The reduction of the network-problem, in as far as the shortest distance calculation is concerned, implied (among other measures taken) a deflation of the full network data-file to a file with data of significant nodes only. See Appendix 2 for INTRANET's basic data structuring.

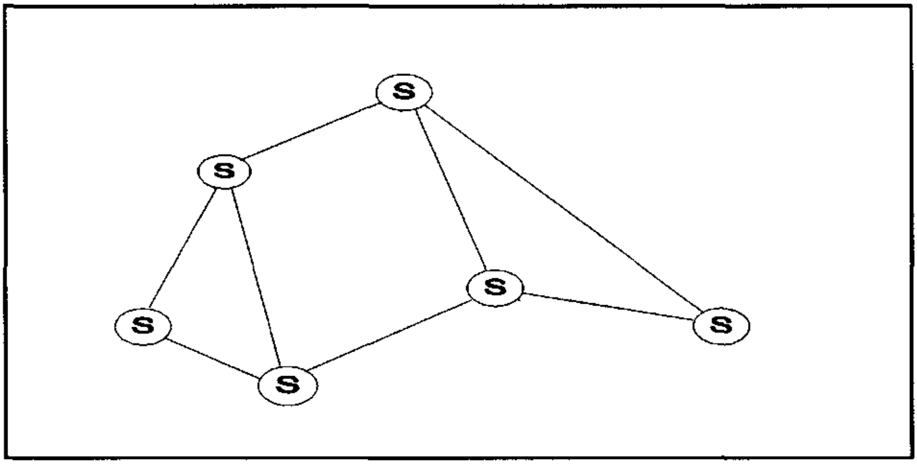



nodes E : end-type node
nodes S : significant type nodes
others : intermediate type nodes
Figure 4-4. An example configuration with three types of nodes.

Figure 4-5 shows the reduced network belonging to this network presented in

areas in the Netherlands, an investigation has shown that a reduction in the number of nodes to 10-20 % is possible.

figure 4-4; it shows the locations of the significant nodes, in between which is drawn a network called the 'significant network'.




S = significant node

Figure 4-5. A network configuration with significant nodes only.

## 4.5 THE CALCULATION OF DISTANCES WITH NETWORK DECOMPOSITION

It is possible to reduce CPU-time by partitioning the network into smaller sub-networks, and by "gluing" the results derived from the calculations within the sub-networks.

Figure 4-6 illustrates an example network, already deflated (see § 4.4), showing its basic (significant) structure. Intermediate and end nodes are left out. Figure 4-6 also shows a decomposition[11] into four sub-networks numbering I-IV as well as tentative shortest distances. How this decomposition should be done is discussed later on.
This figure will be used to explain the procedure to be followed.

11 The INTRANET procedure does not require a decomposition. It is entirely up to the user whether to decompose the network or not. See also § 4.6.

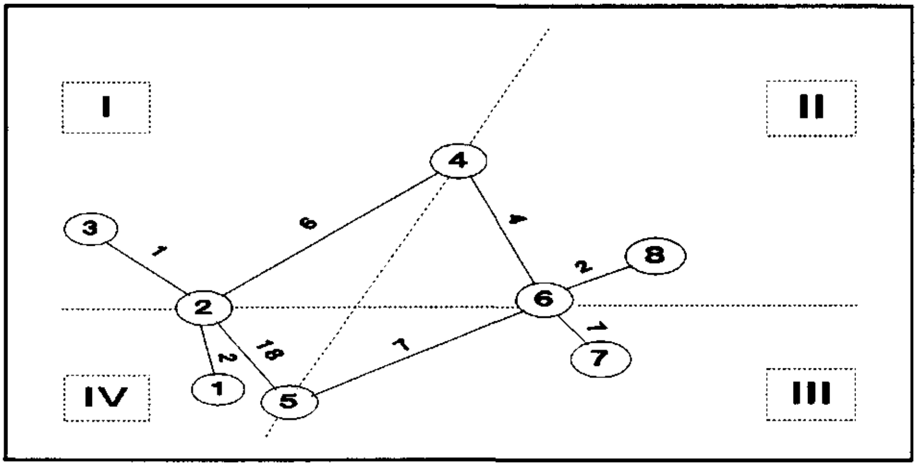



Figure 4-6. A network showing a partitioning into 4 sub-networks.

Note that some nodes belong to more than one sub-network. These nodes play an important role in the decomposition procedure. As they connect two (or more) sub-networks, they will be called 'connecting' nodes. The nodes 2, 4, 5 and 6 in figure 4-6, therefore are called connecting nodes.

The procedure for the calculation of shortest distances to be followed is:

| | |
|---|---|
| step P0: | reduce the network to significant nodes only, make the tentative shortest distance matrix; |
| step P1: | decompose the network into sub-networks; |
| step P2: | calculate the distances between the significant nodes within each sub-network using the shortest distance algorithm; |
| step P3: | store the sub-set of (tentatively known) distances between the connecting nodes in a separate 'connecting nodes' matrix; |
| step P4: | calculate the shortest distances between the connecting nodes in the 'connecting nodes' matrix using the shortest distance algorithm; |
| step P5: | substitute the tentatively known shortest distances as found in step P2 by those found as a result of step P4; |
| step P6: | apply step 2 again; |
| step P7: | bring the results together; end of procedure. |

These steps followed through for figure 4-6, gives the following.

step P0: the tentative shortest distance matrix is:

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 2 | * | * | * | * | * | * |
| 2 | 2 | 0 | 1 | 6 | 18 | * | * | * |
| 3 | * | 1 | 0 | * | * | * | * | * |
| 4 | * | 6 | * | 0 | * | 4 | * | * |
| 5 | * | 18 | * | * | 0 | 7 | * | * |
| 6 | * | * | * | 4 | 7 | 0 | 1 | 2 |
| 7 | * | * | * | * | * | 1 | 0 | * |
| 8 | * | * | * | * | * | 2 | * | 0 |

step P1: divide the total network in sub-networks; let this for example be like in figure 4-6.

step P2: calculate the shortest distances between all nodes within each sub-network:

| I | 2 | 3 | 4 |
|---|---|---|---|
| 2 | 0 | 1 | 6 |
| 3 | 1 | 0 | 7 |
| 4 | 6 | 7 | 0 |

| II | 4 | 6 | 8 |
|---|---|---|---|
| 4 | 0 | 4 | 6 |
| 6 | 4 | 0 | 2 |
| 8 | 6 | 2 | 0 |

| III | 5 | 6 | 7 |
|---|---|---|---|
| 5 | 0 | 7 | 8 |
| 6 | 7 | 0 | 1 |
| 7 | 8 | 1 | 0 |

| IV | 1 | 2 | 5 |
|---|---|---|---|
| 1 | 0 | 2 | 20 |
| 2 | 2 | 0 | 18 |
| 5 | 20 | 18 | 0 |

step P3: store the tentative shortest distances between connecting nodes in a connecting nodes matrix:

| | 2 | 4 | 5 | 6 |
|---|---|---|---|---|
| 2 | 0 | 6 | 18 | * |
| 4 | 6 | 0 | * | 4 |
| 5 | 18 | * | 0 | 7 |
| 6 | * | 4 | 7 | * |

step P4: perform the shortest distance algorithm on the connecting nodes matrix; this leads to:

| | 2 | 4 | 5 | 6 |
|---|---|---|---|---|
| 2 | 0 | 6 | 17 | 10 |
| 4 | 6 | 0 | 11 | 4 |
| 5 | 17 | 11 | 0 | 7 |
| 6 | 10 | 4 | 7 | 0 |

step P5: replace the tentative shortest distances found in step P2 by the values found in step P4;
in sub-network I,II,III no changes occur;
in sub-network IV replace matrix MAT(2,5)=18 by 17

step P6: perform the calculation of shortest distances within each sub-network again;
in the example only sub-network IV changes; replace MAT(1,5)=20 with 19 and MAT(2,5)=18 with 17:

| | 1 | 2 | 5 |
|---|---|---|---|
| 1 | 0 | 2 | 19 |
| 2 | 2 | 0 | 17 |
| 5 | 19 | 17 | 0 |

step P7: bring the sub-networks together; end of procedure
---> result:

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 2 | 3 | 8 | 19 | 12 | 13 | 14 |
| 2 | 2 | 0 | 1 | 6 | 17 | 10 | 11 | 12 |
| 3 | 3 | 1 | 0 | 7 | 18 | 11 | 12 | 13 |
| 4 | 8 | 6 | 7 | 0 | 11 | 4 | 5 | 6 |
| 5 | 19 | 17 | 18 | 11 | 0 | 7 | 7 | 9 |
| 6 | 12 | 10 | 11 | 4 | 7 | 0 | 1 | 2 |
| 7 | 13 | 11 | 12 | 5 | 7 | 1 | 0 | 3 |
| 8 | 14 | 12 | 13 | 6 | 9 | 2 | 3 | 0 |

The following remarks can be made:

- The partitioning is to be done so that the decomposition 'crosses' nodes rather than arcs.
- Step P1 leads towards a partitioning of the total network, so that the shortest route from any node to another within the total network always passes through so-called connecting nodes.
- Step P2 leads to tentative shortest distances between all pairs of nodes within each sub-network.

  Obviously these shortest distances are only valid for each sub-network by itself and not yet for the network as a whole.

- The reduction of the total network to a network of connecting nodes, and using the shortest distance algorithm, leads to knowing the correct shortest distances between these nodes (step P3 and P4).
- Because the shortest route between nodes belonging to different sub-networks, passes through connecting nodes -- as these are the only nodes connecting the sub-networks -- the correct distance between the former nodes depends on the solution found for the reduced network, consisting of connecting nodes only.
- Repeating the use of the distance algorithm per sub-network after introducing the values found for distances between all pairs of connecting nodes (step P3 and P4), leads to finding correct distances between all pairs of nodes of the non-decomposed network.

The question arises of whether a guideline can be given for the decomposition procedure. Generally speaking, it is best to create sub-networks of similar size, that is with each having the 'same' number of significant nodes. The choice of the number of sub-networks can be guided by the performance of the shortest distance algorithm used.
See § 4.6 for a continuation of the answer to the posed question.

## 4.6 ALGORITHMS FOR THE CALCULATION OF SHORTEST DISTANCES

**Basic algorithms**
Several authors have introduced algorithms for the calculation of the shortest routes and related distances between nodes in a N-nodes network. Well known are the algorithms introduced by Dijkstra (1959) and by Floyd (1962) and among others, commented on by Yen (1975). See Appendices 3, 4 and 5 for an explanation of the basic algorithmic procedures. See Appendices 13,14,15 for listings.

The computational burden can be excessive in cases with many nodes. The required CPU-time using algorithms as presented by Floyd, Dijkstra and Yen, is far too much for interactive network analysis with as many as 5000-10000 nodes, a likely amount in land-development projects.

The study has led to comparing the CPU-time needed for the shortest route calculation, when using different algorithms. Table 4-2 shows some values of required CPU-time using the more well-known algorithms of Floyd, Dijkstra and Yen.[12]

For a description of the algorithms used and listing of the programs, see Appendices 3-25. See also figure 4.7 showing the relationship between programs as mentioned in literature and research adaptions made on these.

Table 4-2. CPU-time required (secs) on a VAX-8600 performing shortest route calculations.

| number of nodes<br>algorithm | 50 | 300 | 500 | 1000<br>estimates | 5000 |
|---|---|---|---|---|---|
| FLOYD1 | 0.34 | 126.9 | 669 | 5900 | 788000 |
| DIJKDREV | 0.45 | 140.8 | 725 | 6500 | 897000 |
| ALG023 | 0.26 | 99.6 | 503 | 4500 | 628000 |

Some results of the study for reaching more efficiency are presented in Table 4-3 and figure 4-8a. The estimates for networks with 1000 nodes and upwards have been calculated through regression analysis.

The algorithms ALGASY2 and ALGSSM2 developed, show a substantial decrease in CPU-time needed. This has been reached by a combination of node-reduction techniques, network decomposition and mathematical manipulation. See for listings, Appendices 22 and 25.

Table 4-3. CPU-time required (secs) on a VAX-8600 performing shortest route calculations on INTRANET-algorithms.

| number of nodes<br>algorithm | 50 | 300 | 500 | 1000<br>estimates | 5000 |
|---|---|---|---|---|---|
| ALGSSM2 | 0.14 | 33.0 | 158 | 1350 | 181000 |
| ALGASY2 | 0.17 | 48.2 | 311 | 3200 | 475000 |

12

FLOYD1 refers to the Floyd program, DIJKDREV to a Dijkstra program and ALG023 to a program of Yen.

Figure 4-7 gives an overview of the relationships between the various algorithms tested.

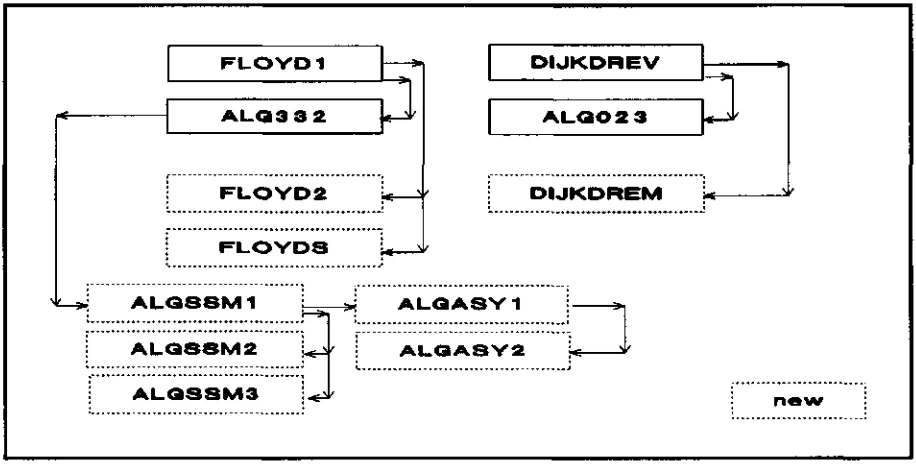



Figure 4-7. The relationship between the various algorithms tested.

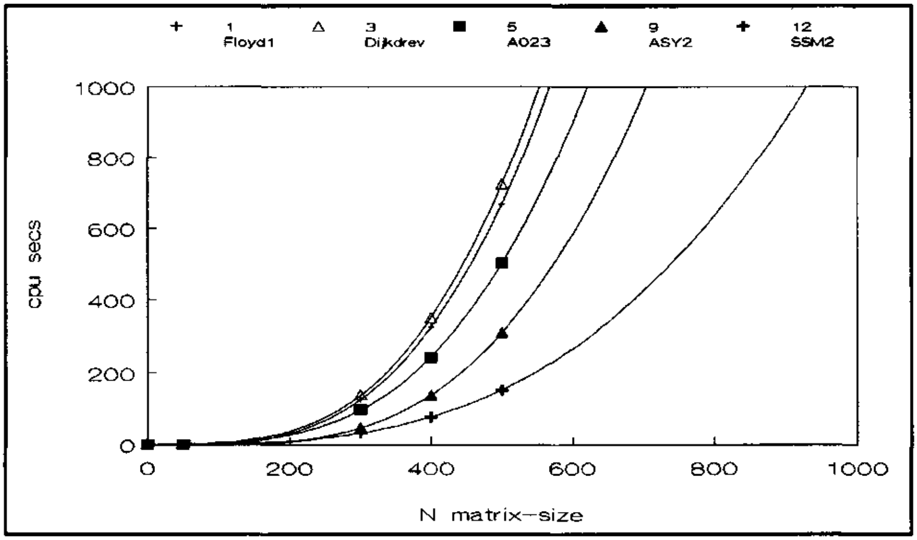



Figure 4-8a. CPU consumption as recorded on a VAX-8600.

**INTRANET algorithms**

**- introduction -**

The algorithms used in INTRANET, have been found by introducing the various techniques found in the algorithms of Floyd and Dijkstra and those upgraded by Yen.

The algorithm ALG332, a Floyd-type algorithm introduced by Yen (1975), has proven to be the speediest, and research has concentrated on this most promising algorithm.

The use of vector mode for row-data in the matrix MAT, found in DIJKDREV and used by Yen in his adaption of a Dijkstra-type called algorithm ALG023, gave rise to the idea of using vector storage mode (VSM) for the full matrix.

In addition, use has been made of a reduction of data to be processed, assuming networks to be non-directed, or rather assuming two-way travel within the road system. The deflation of matrices to approximately half, has been used in conjunction with the use vector storage mode rather than the usual matrix storage mode (MSM). This specific type of vector storage is addressed as a single storage mode (SSM). See Appendices 7, 8 and 9 for more detail.

The transfer of all data from MSM to SSM, with INTRANET, occurs before calling upon the routines for the determination of shortest distances[13]

For symmetric matrices, the developed routine ALGSSM2[14] proves best, while for non-symmetric matrices, the developed algorithm ALGASY2[15] was found more or less as fast as ALG023m, an adaption made on Yen algorithm

13

The necessary data transfer from matrix storage mode (MSM) to vector storage mode (VSM) has to be done only once and has not been included in the calculation of CPU-time needed to perform the various shortest distance algorithms.

14

ALGSSM is a conjunction of ALGorithm and Single Storage Mode. SSM refers to the use of a specific vector storage mode (VSM). See Appendices, 7 and 9.

15

ALGASY is the conjunction of ALGorithm and ASYmmetric for the use of a data storage method for asymmetric data. See Appendices 7 and 8.

ALG023. For listings, see Appendices 15, 20, 22 and 25.

**- symmetric cases -**

Algorithm ALG332, belonging to the group of algorithms found in the literature, and found performing best, has led to an algorithm ALGSSM1 performing less well. However, upgrading is possible, leading to ALGSSM2 and performing better than the original ALG332.

Where appropriate, inner-loop calculations have been taken as far as possible towards the outer-loops. Multiplications for the determination of the index-values have been replaced by additions and subtractions. This adjustment has resulted in a considerable reduction of needed CPU-time. See Appendices 6-9 for more details concerning the upgrading of performances.

In general, in symmetric cases, addresses (indexsk) of Y(indexsk) in single storage mode (SSM), relate to addresses (s,k) of MAT(s,k) as follows:

with Y(indexsk) <-->MAT(s,k)

| | | | |
|---|---|---|---|
| for $s=k$: | indexkk | $= (k-1).(N-k/2)+k$ | (E1a) |
| for $s>k$: | indexsk | $=$ indexkk$+(s-k)$ | (E2) |
| for $s<k$: | indexsk | $=$ indexss$+(k-s)$ | (E3) |

For proof of these equations see Appendices 9 and 10.

The effect of an even further reduction of the set of data, by omitting the diagonal data in MAT(s,k) where values are known to be zero, has been studied. For that purpose a different, adapted MSM to VSM procedure has been used to create a vector Y with less data than before.

ALGSSM3, an adaption of ALGSSM2, was needed for correct data-processing. The results, however, showed an increase in CPU-time needed. This increase has been attributed to the more complicated system of indexing. See Table 4-4 and figures 4-8a,e for (comparative) results. For the listing, see Appendix 23.

**- asymmetric cases -**

As with the derivation of the algorithm ALGSSM2 for symmetric situations, the one for asymmetric cases leads to a substitution of matrix-indexes to vector-indexes, and to a substitution of multiplications by additions and subtractions.

Again a CPU-time reduction has been found.
With index 'indexsk' for the vector-storage-mode of asymmetric networks, and indexes (s,k) for matrix-storage-mode, the following formula can be applied for the transfer of data to VSM; see also Appendix 8:

$$\text{indexsk} = (k\text{-}1).N + s \tag{E4}$$

ALGASY2 is found to be more or less as efficient as ALG332 of Yen, while for symmetric networks, the algorithm ALGSSM2 has been found superior.
For an overview of (comparative) results, see Table 4-4 and figures 4-8a,e.

**- the results in synopsis -**
The performance of the various algorithms has been tested on matrices created at random. Each algorithm used the same matrix to process. The percentage of tentative shortest distances unknown was taken to be 20.

Table 4-4. CPU-time required (secs) on a VAX-8600 performing shortest route calculations.

| number of nodes<br>algorithm | 50 | 300 | 500 | 1000<br>estimates | 5000 |
|---|---|---|---|---|---|
| for asymmetric networks: | | | | | |
| 1. FLOYD1 | 0.34 | 126.9 | 669 | 5900 | 788000 |
| 2. FLOYD2 | 0.19 | 97.2 | 534 | 4900 | 690000 |
| 3. DIJKDREV | 0.45 | 140.8 | 725 | 6500 | 897000 |
| 4. DIJKDREM | 0.49 | 151.5 | 766 | 6650 | 900000 |
| 5. ALG023 | 0.26 | 99.6 | 503 | 4500 | 628000 |
| 6. ALG023M | 0.19 | 64.4 | 337 | 3050 | 427000 |
| 7. ALG332 | 0.17 | 55.3 | 306 | 2850 | 403000 |
| 8. ALGASY1 | 0.28 | 73.2 | 428 | 4125 | 595000 |
| 9. ALGASY2 | 0.17 | 48.2 | 311 | 3175 | 476000 |
| for symmetric networks: | | | | | |
| 10. FLOYDs | 0.18 | 58.1 | 319 | 2800 | 380000 |
| 11. ALGSSM1 | 0.42 | 94.9 | 452 | 3675 | 465000 |
| 12. ALGSSM2 | 0.14 | 33.0 | 158 | 1350 | 181000 |
| 13. ALGSSM3 | 0.18 | 38.5 | 186 | 1575 | 207000 |

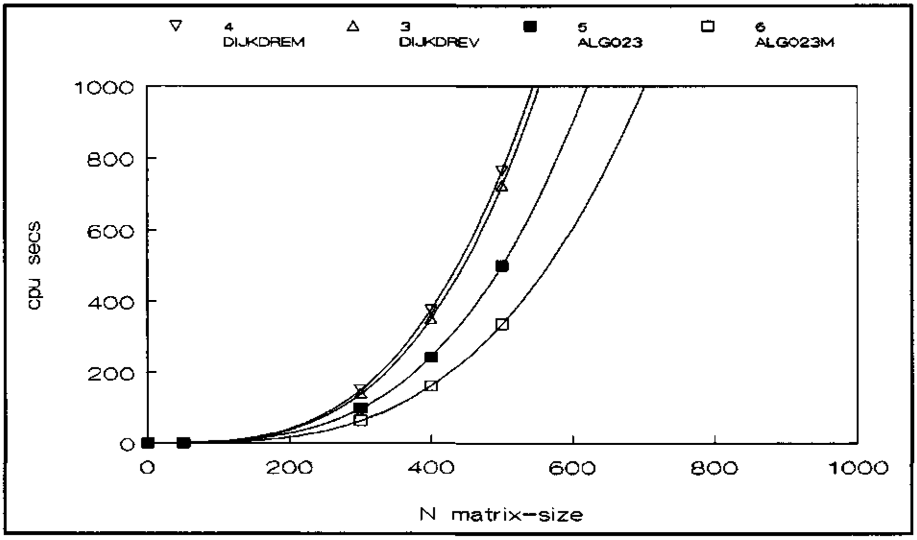



Figure 4-8b. CPU-consumption as recorded on a VAX-8600.

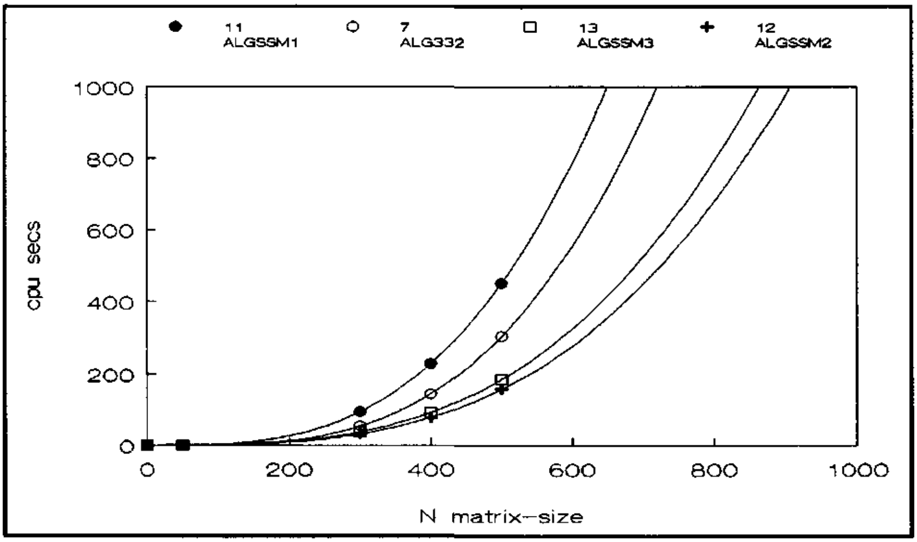



Figure 4-8c. CPU-consumption as recorded on a VAX-8600.

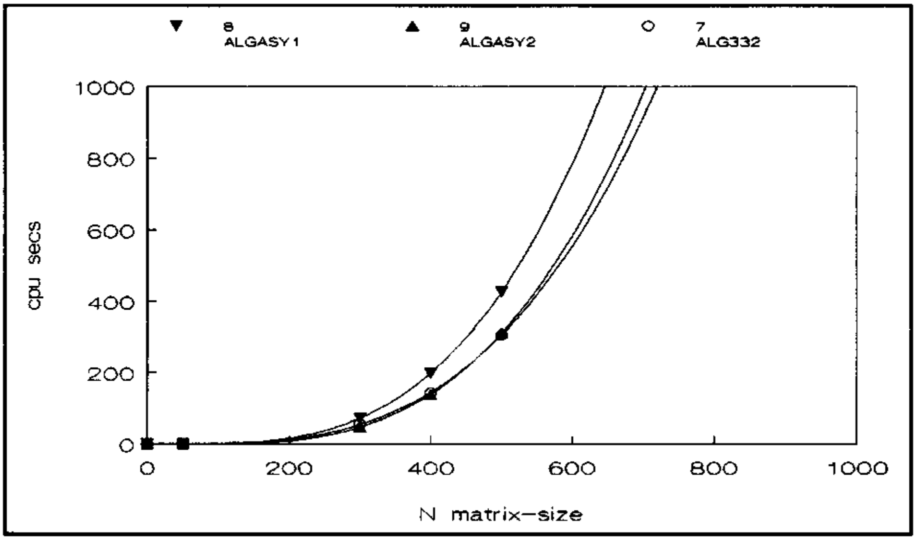



Figure 4-8d. CPU-consumption as recorded on a VAX-8600.

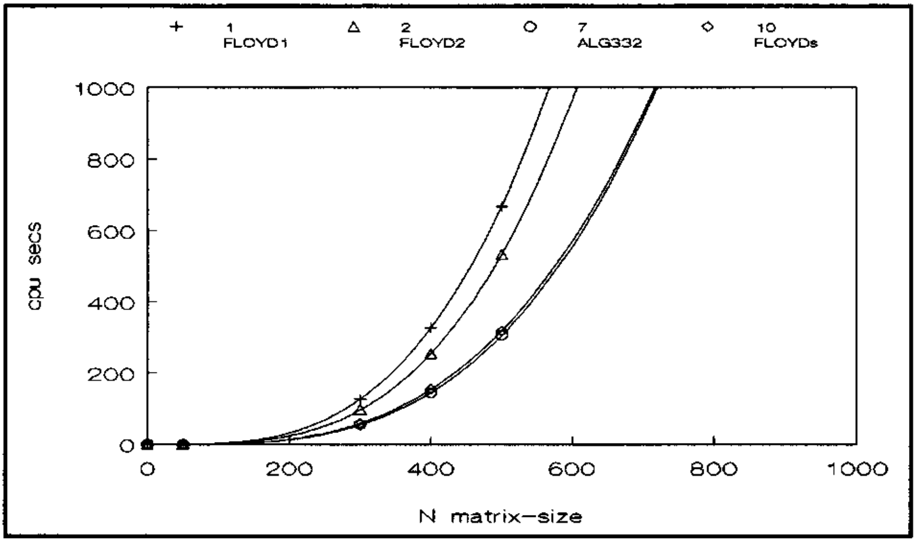



Figure 4-8e. CPU consumption as recorded on a VAX-8600.

The question of into how many sub-networks one has to partition a large network, is not an easy one. Obviously the CPU-need per sub-block is reduced with the number of nodes in such sub-networks. As the decomposition procedure in § 4.5 indicates, the shortest distance calculation for sub-blocks has to be done twice. First, a calculation to determine the tentative shortest distances for each sub-block, and secondly to update the data after the introduction of the results of the calculation done for the connection matrix.
Figure 4-9 shows the results of an investigation into this matter, on the basis of the basic data, as shown in Table 4-4.
The figure shows estimates of needed CPU in case there is no decomposition, against a decomposition into 5, respectively 10 and 20 blocks of similar size. The number of nodes to be stored in the connection matrix has been estimated at (a perhaps somewhat high) 20% .

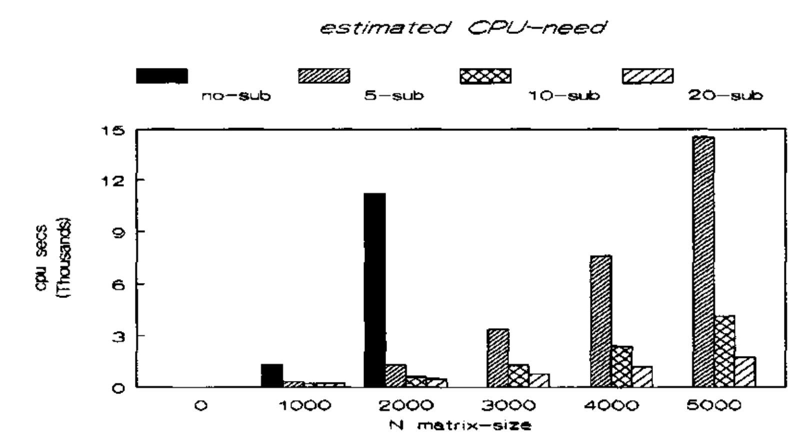



Figure 4-9. Estimates of CPU-time needed when using decomposition and ALGSSM2.

The larger the network, the more CPU-time needed and the greater the need for decomposition. With large connectivity matrices it seems relevant to even decompose those again. In general one should have no more than approximately 150 significant nodes per sub-block when decomposing into 5 or more blocks, to keep into CPU-ranges acceptable.

### 4.7 THE CALCULATION OF DISTANCES

Once distances between significant nodes (see § 4.4 and § 4.5) are known, it is possible to determine the distances between all nodes in the non-reduced network, on the basis of the distances already known between the significant nodes.

Figure 4-10 illustrates a useful network procedure. Let the distance between nodes S and F in figure 4-10 be determined. By comparing the following four summations, the value belonging to the distance d(S,F) is found:

| | |
|---|---|
| i) | d(S,A) + d(A,D) + d(D,F) |
| ii) | d(S,B) + d(B,D) + d(D,F) |
| iii) | d(S,A) + d(A,C) + d(C,F) |
| iv) | d(S,B) + d(B,C) + d(C,F) |

The smallest one reveals the value which was to be found.

INTRANET has the ability to request:
- distances between nodes
- distances between a node and a sub-area[16]
- distances between sub-areas

The determination of distances is performed by calculating and comparing distances of all relevant node-combinations. See also Appendix 29.
With INTRANET, sub-areas can be created graphically on the screen by manipulating a hair-cursor.

16 Any network can be partitioned into a number of constituing sub-networks. Similarly, areas can be divided into sub-areas. The boundary surface of each area is a polygon. With INTRANET, sub-areas are known by the series of (x,y) coordinates of arcs of the polygons.

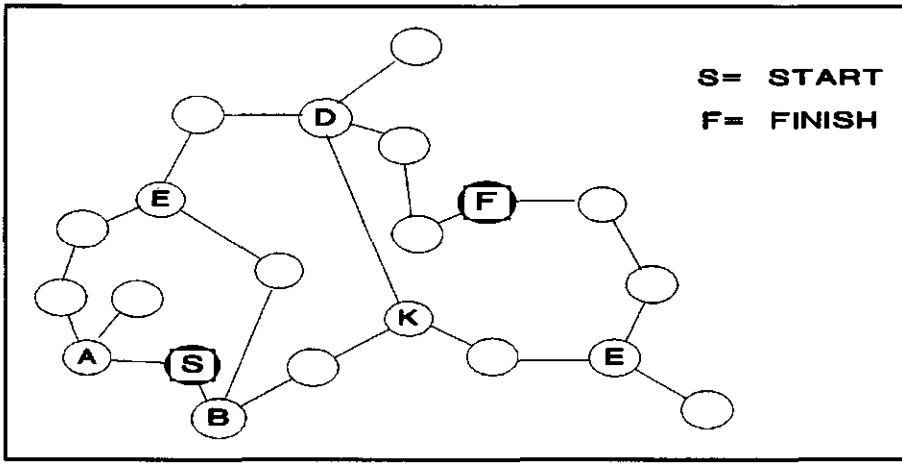



Figure 4-10. A network example.

## 4.8 ROUTING

**Direct routing**

The basic question of determining the route between any node S and any other node F, represents the singular routing problem.
With the help of figure 4-10, it can be seen that the route from S to F leads either through the significant nodes A or B. Comparing the two summations:

i) $d(S,A) + d(A,F)$
ii) $d(S,B) + d(B,F)$

verifies that the route will go through B, that one being the shortest. Once in B, by calculation it can be seen that the route will then go through K. Once there, similar calculations will show that the route leads through D to F.

INTRANET finds the shortest route by comparing weighted distances involved. It can be argued, that people do not always wish to travel the route shortest. Other criteria and other objectives rather than minimizing distance can be involved. If, however, it is possible to translate those objectives in terms of impedance values, then INTRANET again serves its purpose.[17]

For an example of routing-output, see figure 4-11, which shows the shortest route in a network TILBURG between node 3753 and node 1565.

**Complex routing problems**

Planning for travel deals with more complex questions than those of finding the distance and route between some node S and another node F. Most human travel actions represent a more complex routing problem. An example is the problem known as the travelling salesman problem (TSP); the "salesman" is requested to visit more than one address (node) exactly once, for which the total time for travel or distance has to be minimized.[18]

The travelling salesman problem is the problem of finding the best route between S and F, while having to go to A,B,C,D, etc. as well, without any sub-touring:

find: $$\min \left\{ \sum_{i=1}^{n} \sum_{j=1}^{n} d(i,j).x(i,j) \right\}$$

with:

$$\sum_{i=1}^{n} x(i,j) = 1 \text{ for all } j=1,n$$

$$\sum_{j=1}^{n} x(i,j) = 1 \text{ for all } i=1,n$$

17 Let the routing problem be the one of the traveller wishing to pass through the roadsystem by means of the most beautiful roads. In that case, quality attributes have to be known. High quality sections have to be given a low impedance value. Low quality sections have to be given a high impedance value.

18 There are many types of routing problems besides TSP, for instance: MTSP (multiple TSP), CHP (Chinese Postman Problem), SDMV (single depot, multiple vehicle), MDMV (multiple depot, multiple vehicle).

x(i,j) = 0 if arc(i,j) not in path
x(i,j) = 1 if arc(i,j) in path
n = number of nodes
d = distance

The complexity of this becomes obvious where the networks are complicated and large and the route cannot be found intuitively. Examples of the management questions which arise in this problem include the delivery of consumer goods or the hauling of farm-output like fodder, milk, manure, or livestock.

INTRANET has been given a non-heuristic feature[19] which can deal interactively with such TSP questions. One only needs to give the points of departure and finish and up to 10 intermediate nodes[20]. The routing involved will be displayed.
See figure 4-12 for an example of a graphic output of a TSP-problem solved with INTRANET. The routing problem posed, was the one to find the route between a node 1000 and a node 2900 with intermediates given in random sequence: 3000, 1400, 1500 and 1200.

The problem is so-called NP-hard, the problem becoming exponentially more difficult to solve, the larger the number of nodes involved; the problem is not-polynomially bounded (Bodin et al,1983).
The solution for this kind of problem is often sought using heuristic algorithms, instead of algorithms leading to exact solution(s), but requiring considerable

19 The solution has been found by introducing a permutation-routine making all possible route combinations and comparing these.

20 Presently the TSP-module of INTRANET is based on a simple permutation routine giving all combinations of sequences into which the nodes can be put. If N=10 there are 3628800 combinations to be evaluated. With N=50 this would be $3.0414*10^{64}$.

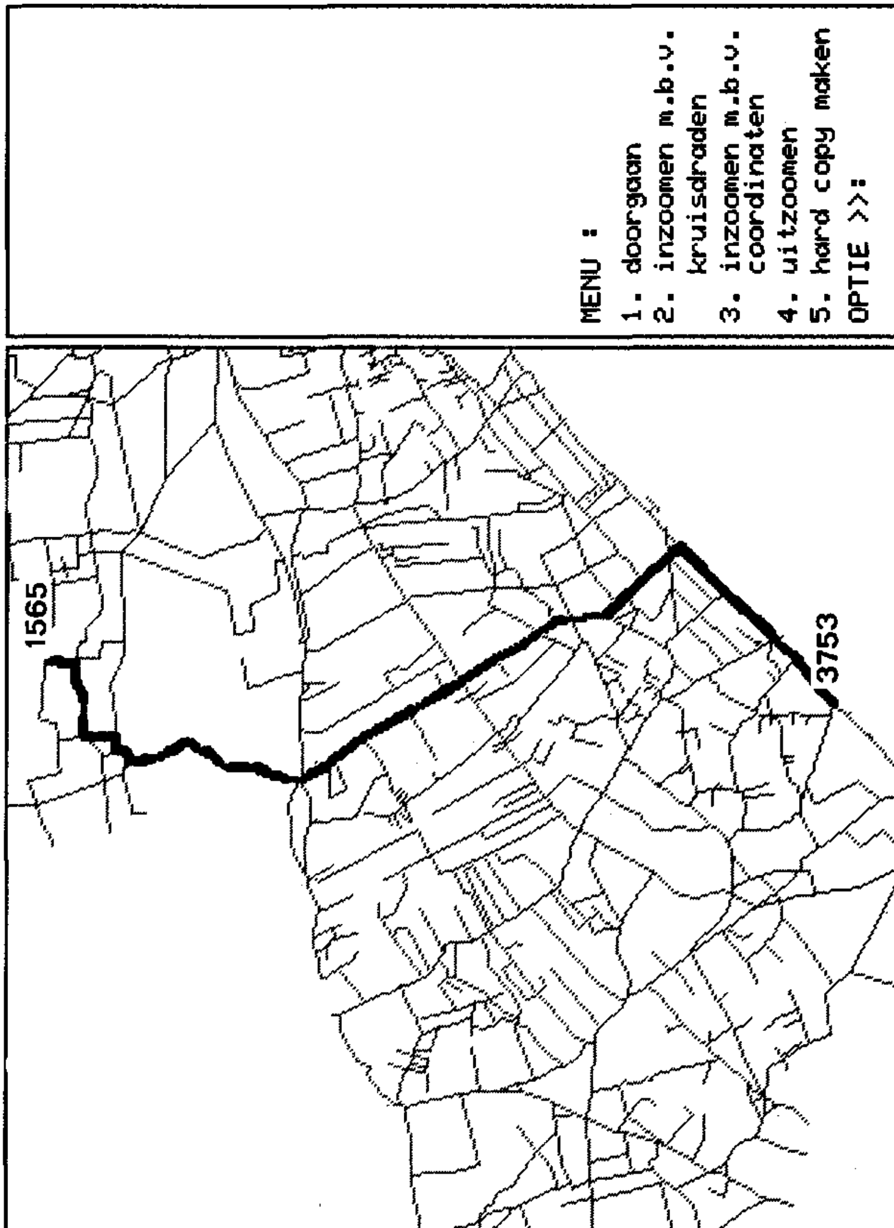



Figure 4-11. An example of a simple routing case.

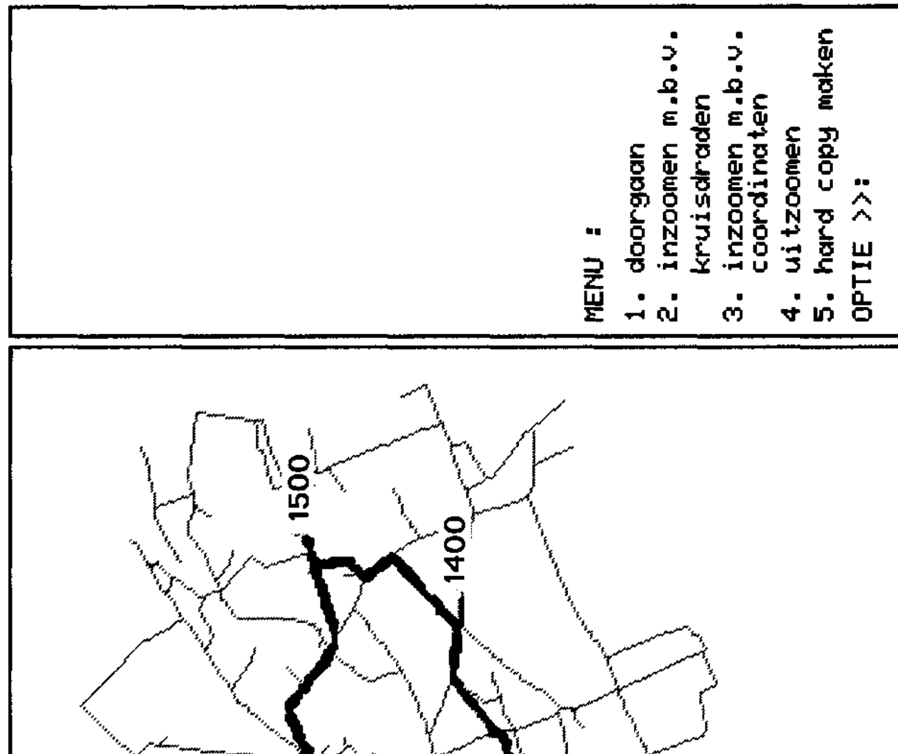



Figure 4-12. An example of a Travelling Salesman Problem.

CPU-time. As of yet it has not been tried to incorporate heuristic algorithms for solving the TSP for a larger number of intermediate nodes involved[21].

## 4.9 ROUTE LABOR PLANNING (RLP)

It can be argued, that real-life problems are even more complex than finding the simple direct or complex routing just described. Real-life problems involve time to travel from one place to another, and time spent during stops. Both labor and time are parameters to be taken into account, and we call these problems: Route Labor Planning problems.
Such planning problems can be seen as a combination of:

- a routing problem; that is, how to decide how to travel
- a labor-allocation problem; that is, how to decide how much time to allocate to what part of the workload and at what time.

INTRANET has been given a RLP-module, requesting the following input:

- the node where to start the travel;
  the point of departure may be the same as the point of finish; at the end of a working period the return to the point of departure has been completed.
- the node indicating where to end.
- the number of intermediate nodes to visit.
- the lengths of sub-working-periods requested at each point that has to be visited (hours:minutes).
- the length of time per working-period (hours:minutes);
  one might think in terms of shifts of 4 or 8 hours.
- the length of time acceptable for working overtime (hours:minutes).
- the type of work, whether discrete or not;
  it is necessary to distinguish between work that has to be done as a unit and work that can be done discretely.
- the velocity while travelling on the standard type road;
  for standard road situations the roads with impedance values of 1 are taken.

---

21

For such the use of the Nearest Neighbor Technique, Nearest/Farthest Insertion technique or those called Two-opt and Three-opt can be used. See Lawler (1985).

- a choice for optimization of time or distance.
  INTRANET has been given two options:
  - option a: optimize for time-saving
    when solutions are found with equal time-consumption, the solution is chosen with least distance involved
  - option b: optimize for distance-saving
    when solutions are found with equal distance-consumption, the solution is chosen with the least time involved.

The RLP-module has been built as the TSP-module (see § 4.8) to which has been added a control over 'time-spent' and 'time-still-available'.
It is necessary to look at time needed to travel to nodes, to the amount of work to be done, and to the time needed to return. Whenever available time runs out, a timely return to the origin S is induced.
See figure 4-13 and Table 4-5 for an example of graphic and alphanumeric output. There, node 3753 serves as point of departure and finish. Travel is to proceed at a speed of 40 km/hr and to pass nodes 1028, 1720, 1301, 2710 and 2761. Work to be done at these nodes: 2:15, 3:05, 0:55, 1:25 and 1:15 hrs respectively.
In Table 4-5 one can read these data as well as the labor-schedule calculated.
*Van .. naar* stands for From .. to, while *echte afstand* stands for actual distance. *Schijnbare afstand* stands for weighted distance. *Rijtijd* refers to time used for travelling, *aankomst ... vertrek* refers to time of arrival, respectively time of departure.
*Verblijftijd* shows the time spent at the node. The table shows 2 working-periods involved (#1 and #2). *Overwerk* refers to doing overtime. The word *deelbaar/niet-deelbaar* refers to work being dividable and non-dividable over time; some work has to be done 'in one piece'.

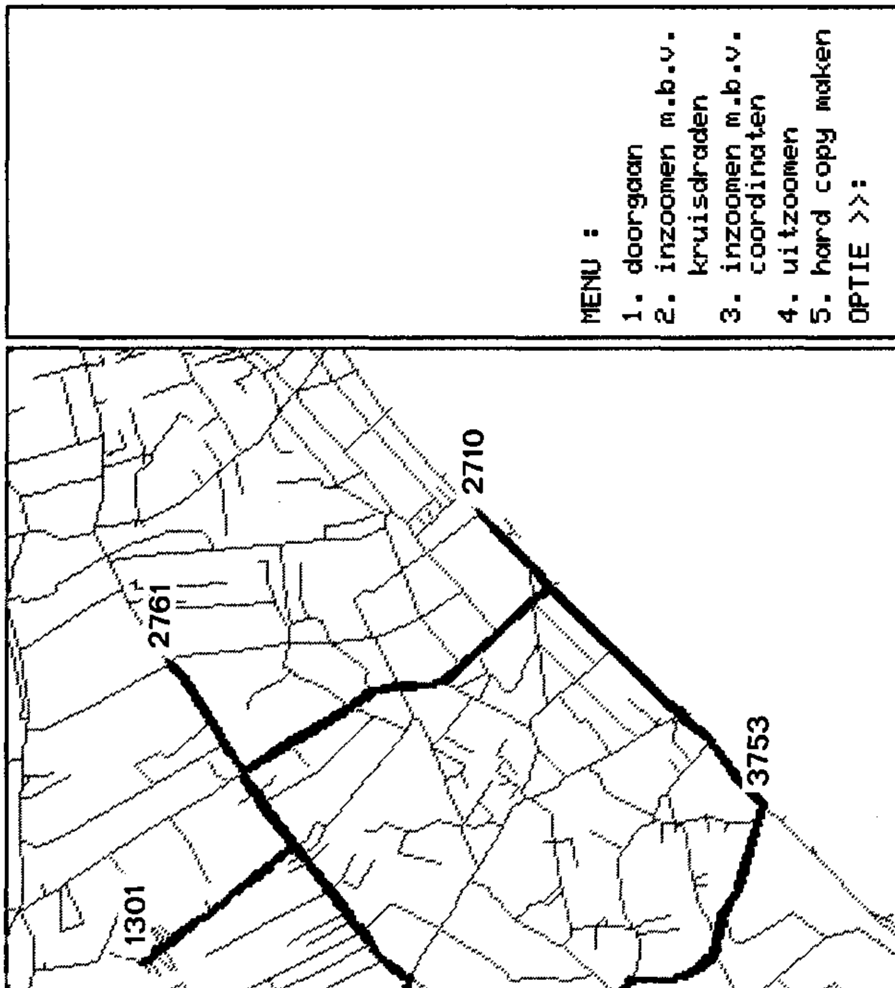



Figure 4-13. An example of a Route Labor Planning case.

Table 4-5. Alpha-numeric output of a Route Labor Planning case.
(for a translation see p.86)

INPUT-gegevens ------------------------------------------------ INPUT

| | | |
|---|---|---|
| 1) optimalisatie van RLP naar | : | min. benodigde tijd (incl. wachten) |
| 2) werkperiode/daglengte | : | 8:00 [ hr:min ] |
| 3) max. hoeveelheid overwerk/dag | : | 0:00 [ hr:min ] |
| 4) werk-/verblijftijd op adressen | : | deelbaar |
| 5) rij-snelheid op de normweg [ s=1] | : | 40.0 km/uur |
| 6) startpunt/depot = 3753 | | eindpunt/finish = 3753 |

| adres-nummer | verblijf-/werktijd hr:min |
|---|---|
| 1028 | 2:15 |
| 1720 | 3:05 |
| 1301 | 0:55 |
| 2710 | 1:25 |
| 2761 | 1:15 |

OUTPUT ------------------------------------------------------- OUTPUT

| van nr | naar nr | afstand echte m | afstand schijnb. m | rijtijd | aan-komst | verblijf-tijd | wacht-tijd | vertrek tijd | over-werk |
|---|---|---|---|---|---|---|---|---|---|
| | | | | ◄--- | hr:min | | | ---► | |
| 3753 | 2710 | 3230 | 3230 | 0:05 | 0:05 | 1:25 | | 1:30 | |
| 2710 | 2761 | 4751 | 4751 | 0:07 | 1:37 | 1:15 | | 2:52 | |
| 2761 | 1301 | 3285 | 5715 | 0:09 | 3:01 | 0:55 | | 3:56 | |
| 1301 | 1028 | 3998 | 6428 | 0:10 | 4:06 | 2:15 | | 6:21 | |
| 1028 | 1720 | 2603 | 3676 | 0:05 | 6:26 | 1:28 | | 7:54 | |
| 1720 | 3753 | 3821 | 3821 | 0:06 | 8:00 | | | 8:00 | |
| # 1 | | 17867 | | | | | | | |
| 3753 | 1720 | 3821 | 3821 | 0:06 | 0:06 | 1:37 | | 1:42 | |
| 1720 | 3753 | 3821 | 3821 | 0:06 | 1:48 | | | | |
| # 2 | | 7642 | | | | | | | |

## 4.10 ACCESSIBILITY

Certain planning questions arise from needing to know what part of the infrastructure can be reached within a certain travelling time. Since time and distance are related, the planning question can also be stated as the need to know what part of the infrastructure falls within a certain range of a point of departure D.

Usually such questions are dealt with by drawing circles on a map, thus determining the area within Euclidean distances. Such practice is an approach to what should be done: the measurement of (weighted) distances within the infrastructure to determine which network links are out and within of travelling range.

INTRANET has been given such a RAD(ius-)module, allowing for :

- a calculation of nodes, within (any given) travelling range[22] from (any given) node D, and
- the display of links involved

The given module is based upon a determination of whether the distance from the given 'center'-node to any branch within the network, lies within or outside the given range. If only part of a network-branch lies within, that is, if only one node of the branch lies within range, the end-position within the link is calculated. See for an example of output, figure 4-14.

INTRANET has also been given a somewhat more complicated 'accessibility' routine than the one just above, more fitting the physical planning problem of determining the quantity 'isolation' of a number of locations L as related to for example, a highway. This question is one of determining the (weighted) distance of each location L(i) to each nearest entry to the highway.

Figure 4-15 is an example of output for such a question. The highway is highlighted; the shortest routes from the locations L to the highway are displayed and colored as classified. The legend shows the classification.

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22 As INTRANET determines weighted distances between nodes, the travelling range in fact is the weighted travelling range.

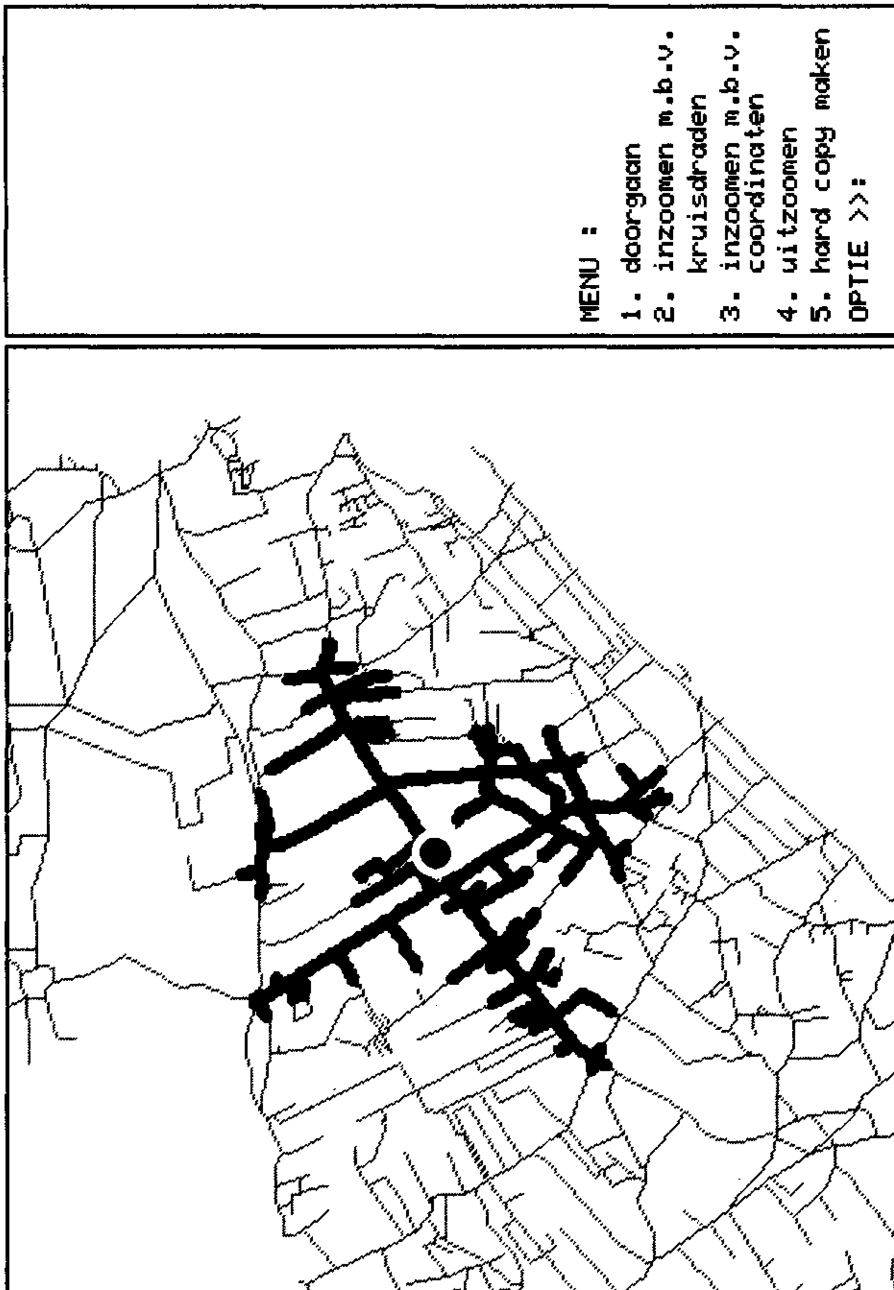


Figure 4-14. An example of output of the INTRANET-module RADius.

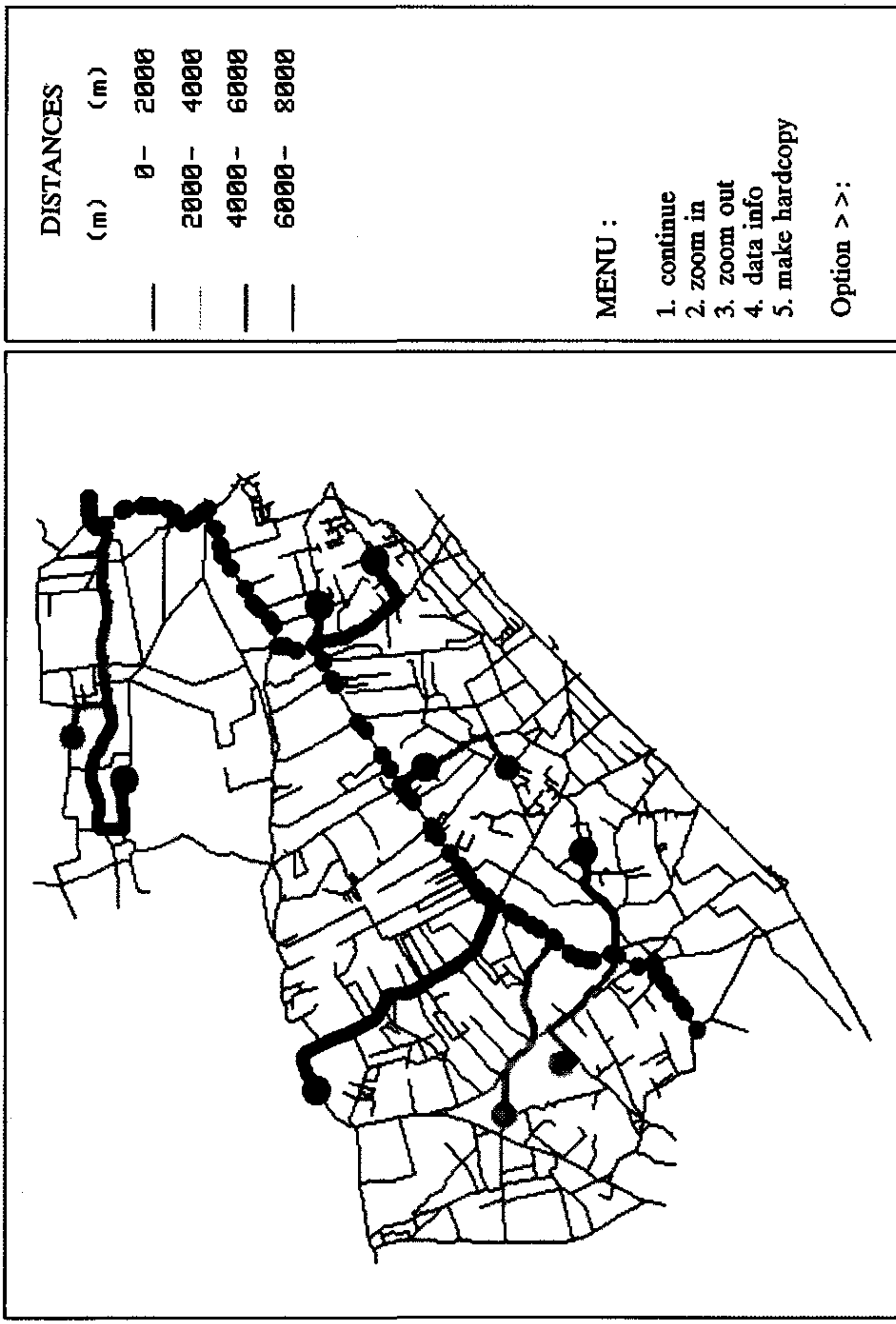


Figure 4-15. An example of an accessibility classification.

## 4.11 TRAFFIC CALCULATION

In the preceding chapter § 4.7, an explanation was given of how to determine the route belonging to the (weighed) shortest distance between any two nodes, S and F, within a network. With many S-to-F activities, that is, 'much traffic on the road', the questions arises of *how much* traffic occurs where.
For this question, INTRANET has been given a module recording which network links are in use and how much traffic flow exists. Per branch is determined how much traffic flows (in what direction).
As of yet no graphic output routines for this module have been added.

## 4.12 EDITING OF INPUT DATA

In an interactive planning setting, it should be possible to create new networks within a short time, thereby using them as new input for quantifying the effects of change in parameters. New data-sets may result from:

- adding/deleting nodes when a change in the collection of places of interest is valid
- adding/deleting arcs for changes in road availabilities
- alterations of impedance-values for change in accessibilities

INTRANET has features for updating input-data alpha-numerically and updating input-data graphically.
The graphic module presently operates in combination with interactive query functions for showing numbers of nodes and showing impedance values used with the network.

## 4.13 INPUT-ANALYSIS FEATURES

Before INTRANET can be put to use, for example, for the calculation of distances and the optimization of a routing, the input-data should be screened on preparation faults. When newly acquired digitized data do have flaws, it is necessary to update the data. For scrutinizing the data, as well a for a more general, visual inspection and interpretation of the data, INTRANET has been supplied with some input-analysis features.

One can choose to:
- display the network
- display the network with differentiation to impedance values
- display parts of the network, that is, only those connections with certain impedance values
- display the network and color nodes according to a classification related to the number of links per node
- have shown the geographic position of node ...'nr'... in conjunction with a display of the network
- zoom for detail
- show (x,y) values of coordinates

## 4.14 SOME OPERATIONAL ASPECTS

**The interactive use of INTRANET**

INTRANET has been created as an interactive program. Due to menus, a fast and flexible use is possible. Editing features allow input-data to be altered and the fast calculate/planning routines make it possible to use the program as a tool for impact analysis. The various output features allow different output--mapping for use as report-material or further study.

**Output**

Output can be generated in various forms, according to the features of the different menu-options.

Zoom-functions allow the creation of overview and close-up detailed information, while hardcopy output allows mapping on paper and overhead sheet.

Overlay-mapping, that is, the adding of (digitized) background data, when they are available, is possible.

Various color-options allow various output-styles.

**Menus in general**

INTRANET has been fitted with menus to facilitate the user. They easily lead out through all the features. No special system query language is needed.

Once INTRANET has been started, the user gets a main-menu from which to choose. In general, this leads to follow-up menus where again one must make a choice. In this manner a complete option-hierarchy exists and the program-user has to find his/her way within. Generally speaking, there is only an up an a down and no short-cuts.

**Input requirements**
The programme INTRANET can operate only when digitized network data are available. A link data-file with impedance values (in a certain format) however, is all that is needed.

**Hardware/software**
INTRANET has been written in FORTRAN/77 using VAX/VMS (Huijskes, van Lemmen (1986); van Staveren (1987); Lapoutre (1991)). The GKS-UNIRAS toolbox of European Software Contractors has been used for the graphic parts of INTRANET. INTRANET operates on terminals of the type TEK42xx.

## 4.15 SUMMARY AND CONCLUSIONS

The rural road system is an important object within land-development projects, because it is that part of the land which ensures access to other pieces of land. Thus, it plays an important role in the overall use of land-units.
Route-analysis is basic to many land-management questions, whether for purposes of optimizing routing for various landuses or for management of the system itself.
The rural road system can be modelled as a network with nodes and links, with the nodes representing places of interest and positions of transition within the network, and the roads as links of the network.
Calculations concerning the distances between nodes and the routing between them is a computational burden when networks become large.

With INTRANET, procedures have been found to reduce the mathematical burden, making it possible to use INTRANET as an interactive tool for route analysis in (for example) land-development projects.
INTRANET has data-editing, calculation and planning, and mapping facilities. The program allows the calculation of distances, the determination of shortest routes, both simple and complex, and some labor-planning optimization.
Accessibility is based upon using the network, taking impedance values into

account rather than Euclidean distances.
INTRANET can be used for developing land-development plans, and allows impact-analysis for routing, for access to and from and for time involved. Layout and quality of the road sections translated to impedance values form the network used.

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## 5. ECONET --
**Planning tool for ECOlogical NETwork analysis**

### 5.1 INTRODUCTION

Nature worldwide is under pressure and areas with natural conditions are rapidly diminishing. More and more areas are becoming desertified, and more and more areas are becoming polluted; a general over-exploitation of plant- and animal life can be noticed (NBP,1989). The Brundtland report (1987) states: " The planet's species are under stress. There is a growing scientific consensus that species are disappearing at rates never before witnessed" and "...Diversity of species is necessary for the normal functioning of ecosystems and the biosphere as a whole".
Acknowledgement of this type of human use of land has deepened the belief that strategies have to be set for a wiser use of raw materials, species and ecosystems (Brundlandt,1987; NBP,1989; de Zeeuw,1990).
At issue, for landuse planners, is how to set out strategies. For instance, present-day technology increases the intensity and reduces the diversity of uses for purposes like agriculture, housing, and traffic, and so doing, mankind creates not only a widespread differentiation in ecological quality, but also contributes to isolation of those areas having little or no anthropogenic pressure. With technology increasing at the rate it does, human power to radically alter the countryside, has vastly increased and "unintended changes are occurring in the atmosphere, in soils, in water, among plants and animals and in the relationship among these all" (Brundtland,1987).

In order to be able to offset ecological perils, there still is a great need to increase the scientific knowledge concerning:

i) the effects of hydrological processes like acid deposition, eutrophication, withering, and sweetening breakwaters;
ii) the effects of pollution,
iii) the effects of the decrease of natural areas like edges and hedges, shrubs, and small woodlands; and,
iv) the effects of parcellation on the survival of populations of plant-, bird and animal life.

As for iii) and iv), it is well understood that nature is dependant on relationships between natural objects. Birds and animals, not only fly or creep within hedges, shrubs, and small woodlands, they also "leap" from one niche to another, thus recolonizing these "islands of nature", located within areas of human concentration.

Van Wijland (1988) pleas for an increase of planning and for the realization of a three-tier structure within this field:

- the realization of ecological structures, first level
  areas epicentral with completely self-regulating nature, consisting of large complexes with optimal habitats[1] (e.g. woods and highland moors, wetlands, brookland systems including catchment area), with linking corridors and stepping stones.
- the realization of ecological structures, second level
  areas related to those of the first level, which are medium sized, usually accompanying man-made infrastructures like estates, afforestated areas, and watercourses.
- the realization of ecological structures, third level
  areas related to those of the second level, which are small sized, and are fitted in with more anthropogenic landuse forms; aim: the realization and the reconstruction of more natural conditions along groves, ponds, reeded banks, and the like.

For landuse planners key questions arise such as: Where to find and/or locate these structures? Where to defend areas against other landuse claims? Other specific questions include: How and where to locate the new highway needed? Is it possible to meet traffic demands and ecological demands at the same time? It is possible to pinpoint where 'bypasses' for animals might offset detrimental effects of anthropocentric landuse?

Research into such planning questions has brought the creation of a set of computer-programs called ECONET. These programs have been designed to

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1 Habitat; areas within a landscape in which the concerned species can feed itself and reproduce.
The landscape itself can be seen as an entity with optimal, marginal and non-habitat areas.

achieve a better understanding of where the 'ecological network'[2] is located and which topographic relationships between ecological objects are most important.

The ECONET programs only deal with the spatial relationship between ecological objects, based on their location and form. The programs do not deal with such aspects as hydrology, climate, temperature, or habitat requirements. They are restricted and deal solely with aspects of accessibility, remoteness and isolation, and contribute therefore only in the field of concerns iii) and iv) mentioned earlier.

## 5.2 ECOLOGICAL NETWORKS

In 1866 Haeckel introduced the notion of ecology as being the science that studies the relationship between organisms and environment (Bakker,1981). Later, the notion expanded to specify the relationships between the various organisms. Systematic ecological research, however, has been restricted to the relationships between biosphere and primary physical conditions of land, such as the relationships of plant-life to aspects like temperature, humidity, and the availability of water and nutrients. More recent is the call for research involving spatial aspects, likely induced by a growing isolation of organisms due a decrease in the number of natural biotopes and increased geographic remoteness.

MacArthur and Wilson (1967) discuss the theory of island biogeography and the importance of movements of immigration related to the proliferation and extinction of species. The dispersion of organisms (for example animals) from within local populations, may be the result of species being too densely populated or the habitat becoming unsuitable for the life-cycle of the organism. The chance of extinction of local populations is larger when the population is small, and remote from other populations. Size of habitat area and the spatial arrangement within the landscape are parameters influencing the populations (Diamond,1984; Opdam,1987). These relationships have been noticed for birds (Krebs,1971; van Dorp and Opdam,1987), for small mammals (Petterson,1985; van Noorden,1987; Askins,1987), for amphibians (Laan and Verboom,1986), for

2 Ecological network: the set of habitats and corridors in between them.

beetles (van der Eijk,1987; Kareiva,1987; Lawrence,1988) and for butterflies (Mallet,1986; Wijnhoff,1990). Unfortunately, many parameters for the most critical species are unknown and generalizations from empirical data are hazardous.
Recolonization of habitat areas depends on the degree of isolation (distance between and quantity of habitat area in surrounding areas), on characteristics of the species involved, and on the quality of the habitat into which a species is or can be settled.

## 5.3 MODELLING ECONET

For landuse planners dealing with spatial parameters, the effect of changes in distance between ecological objects is a critical study. It involves size, form and location -- the parameters which can be influenced by land-development projects. Isolation is a measure of the difficulty in going from one object to another. It involves distance[3] and the difficulty endured by species when dispersing.

The set of current ECONET-models takes into consideration (in various degrees): size, form and location of objects involved[4].

- ECONET1;
  this model takes into account 'node' habitat areas within non-habitat areas; it does not take into account any barriers that might exist in between the habitat areas.
  This model can be used for plants with multi-lateral dispersion characteristics.
  See § 5.4.

---

3 Distance belonging to the pathway used between the ecological objects.

4 Obviously more parameters than the mere topographic parameters are of importance. For individuals, travel also means being prayed upon and the one route might be more safe than the other. Such aspects however are beyond the scope of the present study.

- ECONET2;
  this model is an adaptation of ECONET1, making use of a pre-determined network along which dispersion between eco-objects is thought to occur. Multi-lateral dispersion is thought to exist only within the pre-defined network.
  This model can be used for plants under conditions where dispersion-channels are known beforehand. See § 5.5.

- ECONET3;
  this model is more complicated and also is based upon ECONET1, taking into consideration form and size of eco-objects and those of obstructions within the non-habitat areas.
  This model fits the situation of animals and birds; dispersion is taken to be fully multi-lateral, but with no-access in barrier-objects. See § 5.6.

In the chapters explaining the more complicated models, reference is made to explanations given in the more simple models.

## 5.4 ECONET1

**Basic model assumptions:**

a) It is assumed that ecological objects can be reached by 'crow-flight', which is the process of dispersion which occurs along straight-line corridors between objects. Barriers in between eco-objects do not exist.

b) It is also assumed that ecological objects can be spatially represented on a map by points or dots; see for an example, figure 5-1.

Figure 5-1 is an example of a presentation by ECONET1 of location-data concerning the plant *Centaurea Jacea* (CENJAC) in an area called Binnenveld. The dots represent the locations where it has been found within the area. These sites are being displayed together with the ditches present in the research area.

**Isolation, remoteness, distances and ecological infrastructure**

The process of dispersion most easily occurs along the set of connections between neighboring habitat-areas. From the viewpoint of species, rather than

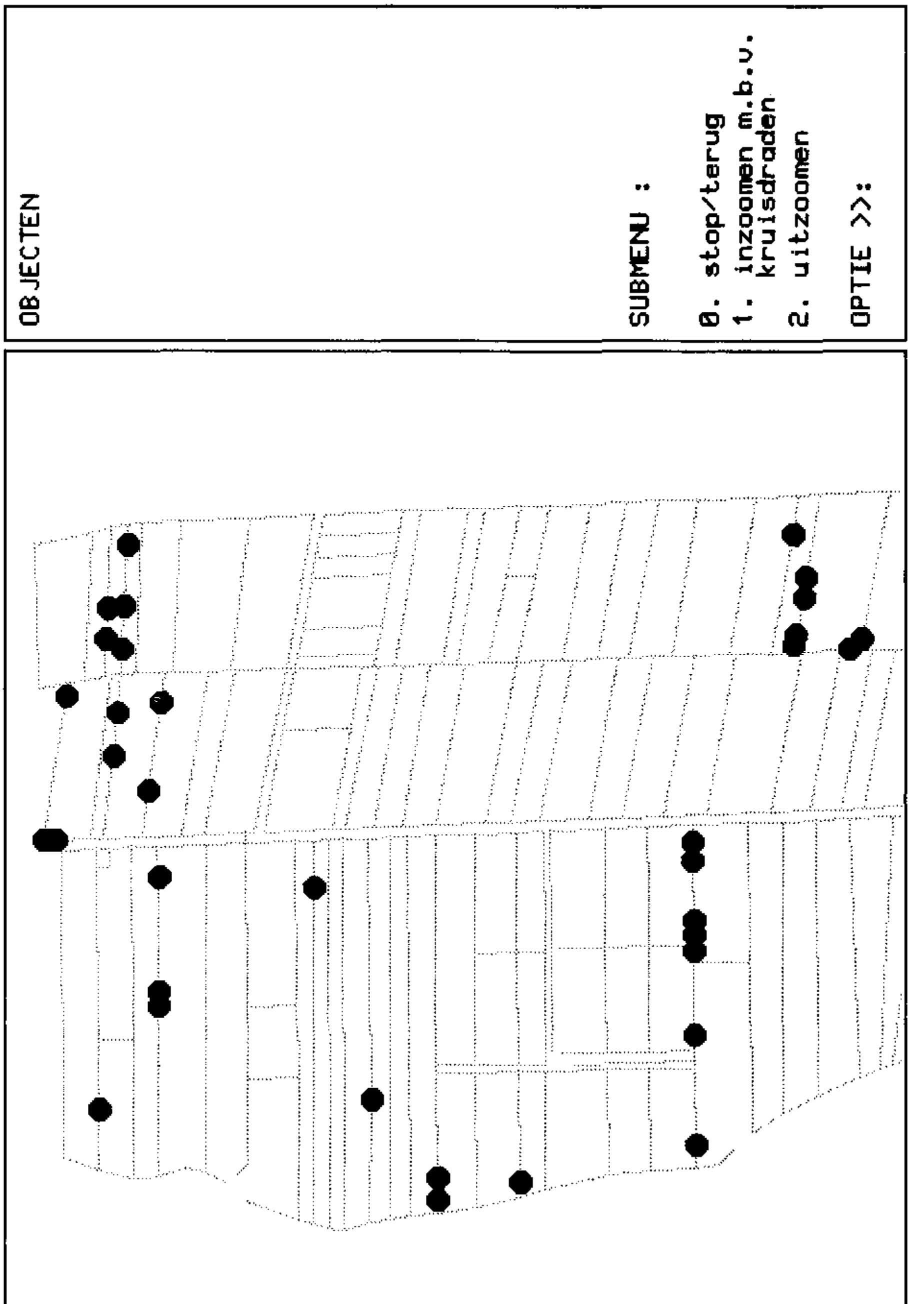


**Figure 5-1. Locations of CENJAC within the area Binnenveld.**

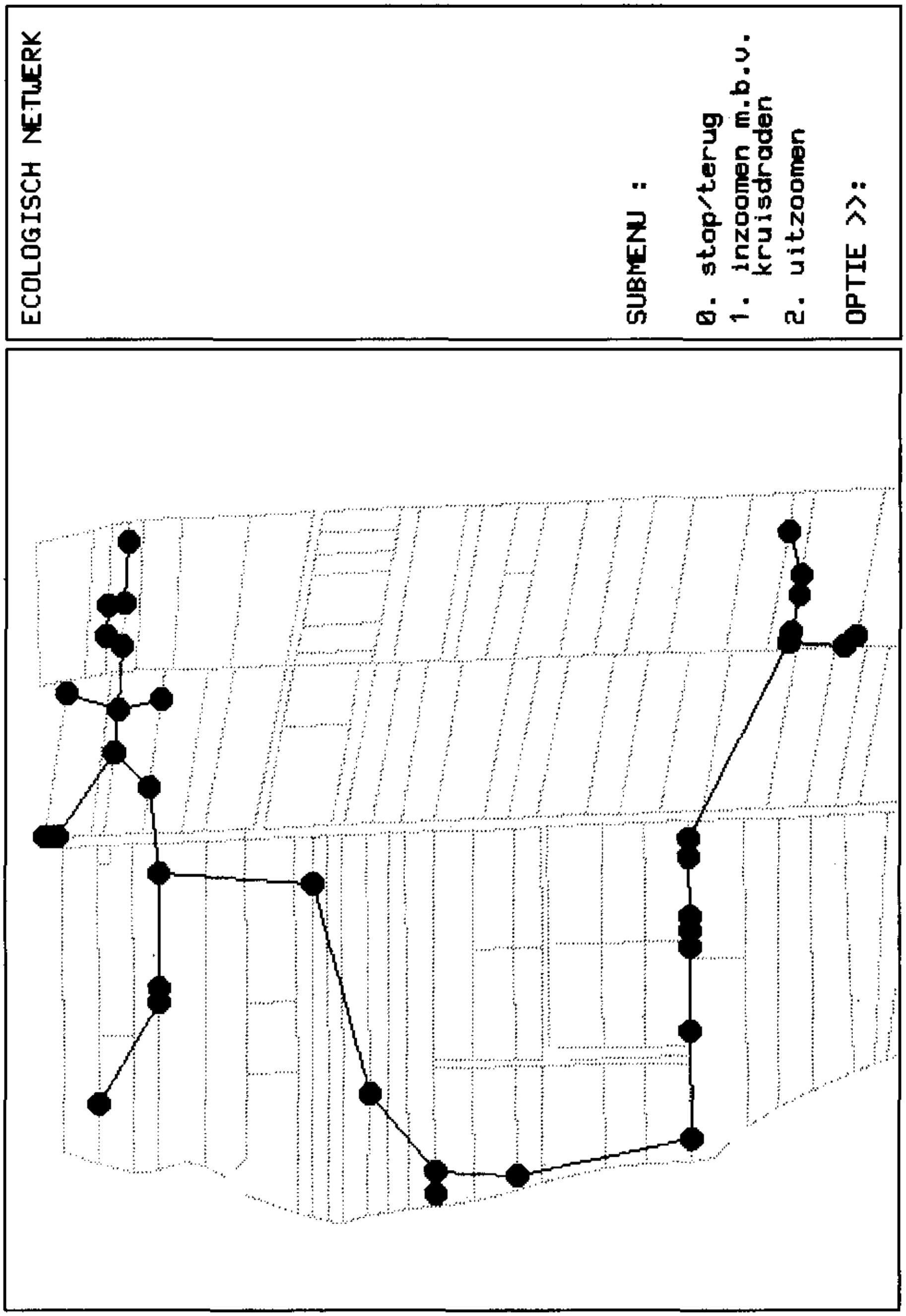


**Figure 5-2. The ecological infrastructure of CENJAC in the Binnenveld-area.**

that of a specific organism, going to the nearest neighboring habitat-subarea is assumed to be less strenuous than going straight to the more remote habitat-subareas.
Basically, with ECONET, such stepping-stone connections are assumed to be of greater importance than the Euclidean connections. For planners therefore, the task is to find the most important stepping-stone connections and then to propose landuse plans based on such findings.

Habitat-areas within non-habitat areas can mathematically be interpreted as a network model with nodes and links, the nodes standing for the habitat-areas, and the links standing for the connections between these areas.
Of interest is the set with all possible connections between all nodes. But of specific interest is that sub-set for which the sum of link-lengths is smallest. The latter is the model-equivalent of the set of nearest neighbor routes. Mathematically this is the so-called minimum spanning tree[5]. See figure 5-2 for an ECONET1-example based on the CENJAC-data.

Within this study this (adapted) sub-set will be addressed as the ecological infrastructure, understanding the limitation that it is solely based on distance/ remoteness of eco-objects to one another.

5

To explain the meaning of minimum spanning tree, use is made of the term 'graph'.
Here a graph G(N,E) is meant to consists of two things:
- a set N whose elements are called nodes
- a set E of unordered pairs of nodes (denoting the connection; also called edges/links)
Graphs which are cycle-free -- each pair of nodes is connected by exactly one path only -- and in which the number of pairs is one less than the number of nodes, are called trees.
A spanning tree is a subgraph of G, if it is a tree and includes all the nodes of G.
A minimum spanning tree is a spanning tree in which the sum of the weights (e.g. the lengths) of its edges is minimal among all spanning trees of G.
See also the next footnote.

The minimum spanning tree can be found by sorting all possible links in order of length and taking links in ascending order until all nodes have been gathered[6]; output: file SORTLINKS.
The lengths of links -- i.e. distances between nodes, d(i,j) -- can easily be calculated on the basis of known (x,y) coordinate values of the nodes i and j and formula:

$$d(i,j) = [(x_j - x_i)^2 + (y_j - y_i)^2]^{1/2}$$

The series of links within the minimum spanning tree, can be stored in a data-file NETMAT (NETwork MATrix).
At present, remoteness of objects is taken to be equal to distances. As of yet no weighing factors other than the Euclidean distances are taken into consideration[7].

**Isolation and vulnerability**
When ecological objects become isolated, with organisms no longer frequently recolonizing ecological objects, the ecological complex becomes vulnerable. From a planning point of view it is important to know those eco-objects which are most vulnerable to being (or becoming) isolated. Obviously, the object most remote from other objects, is the one most isolated. The object most remote but one, is the object most vulnerable but one. For the computer the task to find this sequence and the objects involved.

The ECONET model has been created so that it calculates and displays the eco-object most remote from other objects. See figure 5-3 for an output example.

6

Where two or more links are of equal importance (read: weight or length), the complete set of these equal links has to be included into the set constituing the "minimum spanning tree".

7

There is reason to believe, however, there is no strict linear relationship with distance, having to put more weight (i.e. resistance-value) the further the eco-object to be reached.

The calculation and display are based on a processing of the distance-data and those sequenced in SORTLINKS for a clustering of eco-objects. Basically two different files, SM1 and SM2, are constructed. SM1 is a matrix which uses dummy-nodes to keep track of which eco-object is closely related to another object. SM2 keeps track of relationships by means of storing information on the dummy-nodes. See Appendix 26 for more details.

**Coherence of eco-objects**

As mentioned above, the ecological infrastructure has been found by arranging the shortest connections between ecological objects.

The going to and from one ecological object to the other is easiest when remoteness is smallest, but whether objects are related ecologically depends on the characteristic of the species and organisms studied as well.

Within this study, with distance the relevant parameter, eco-objects lying closely together, are taken to have a greater (potential) coherence than those lying far apart. The ECONET programs have been given modules allowing a display of the coherence as a function of distance, to be interpreted as distance that can be coped with by the species studied[8].

The eco-objects within reach are displayed as a cluster[9]. In terms of interest of species, such a group of eco-objects can be referred to as the (potential) meta-population[10]. See figures 5-4 and 5-5 as examples of output of this module.

---

8

If a habitat area H is in reach by a population occupying eco-object A, -- the dispersion-rate allowing the distance between A and H to coped with -- any habitat-area B within similar distance to H, is taken to be in reach from A.
B is then taken to be a new H, for which the process is repeated until no further objects are in reach.

9

From a map point of view, nodes and links are shown.

10

Meta-population; a set of spatially divided local populations, connected through dispersion.
The meta-population to take into consideration depends on the dispersion-rate of the species involved.

The number of eco-objects within such cluster-sets depends on the dispersion-rate, for example 1-2 m/yr for grass (Verkaar et al,1983), 4-11 m/yr for thistles (Levin and Kerster, 1974), up to 250 m/yr for butterflies (Mallet, 1986), and up to 10 km/yr for flying beetles (Haeck, 1971).

The larger the dispersion rate, the larger the distance and the more objects that make up a meta-population. The top of figure 5-6 (output of the statistical ECONET-module based on the data of figure 5-1) shows the number of clusters as they relate to the dispersion-distance. The bottom figure shows the percentage of eco-objects connected into clusters (meta-populations), also as a function of dispersion-distance. The spatial distribution of eco-objects, as related to the dispersion process, can thus be displayed.

**Model interpretation and use for landuse planning**

With ECONET the finding of the most important dispersion routes can be interpreted to mean 'stay away' from these 'corridors' when trying to meet demands other than those for nature.

Areas not indicated to belong to the most important dispersion routes can be taken as less important for the dispersion process. These areas therefore can be considered as being areas better to serve other purposes than those for the dispersion of species.

The weaker eco-objects, that is, the ones being vulnerable because of becoming isolated easily, can also be traced with ECONET. Landuse plans can be developed accordingly and might include the creation of new stepping-stones within the vicinity of such isolated objects. Perhaps an increase in area of the isolated objects is called for, thus decreasing their vulnerability.

Deleting or adding eco-objects to the sets used, and letting ECONET determine the most interesting dispersion routes and vulnerability of objects, gives insight into the impacts of proposed land-development measures.

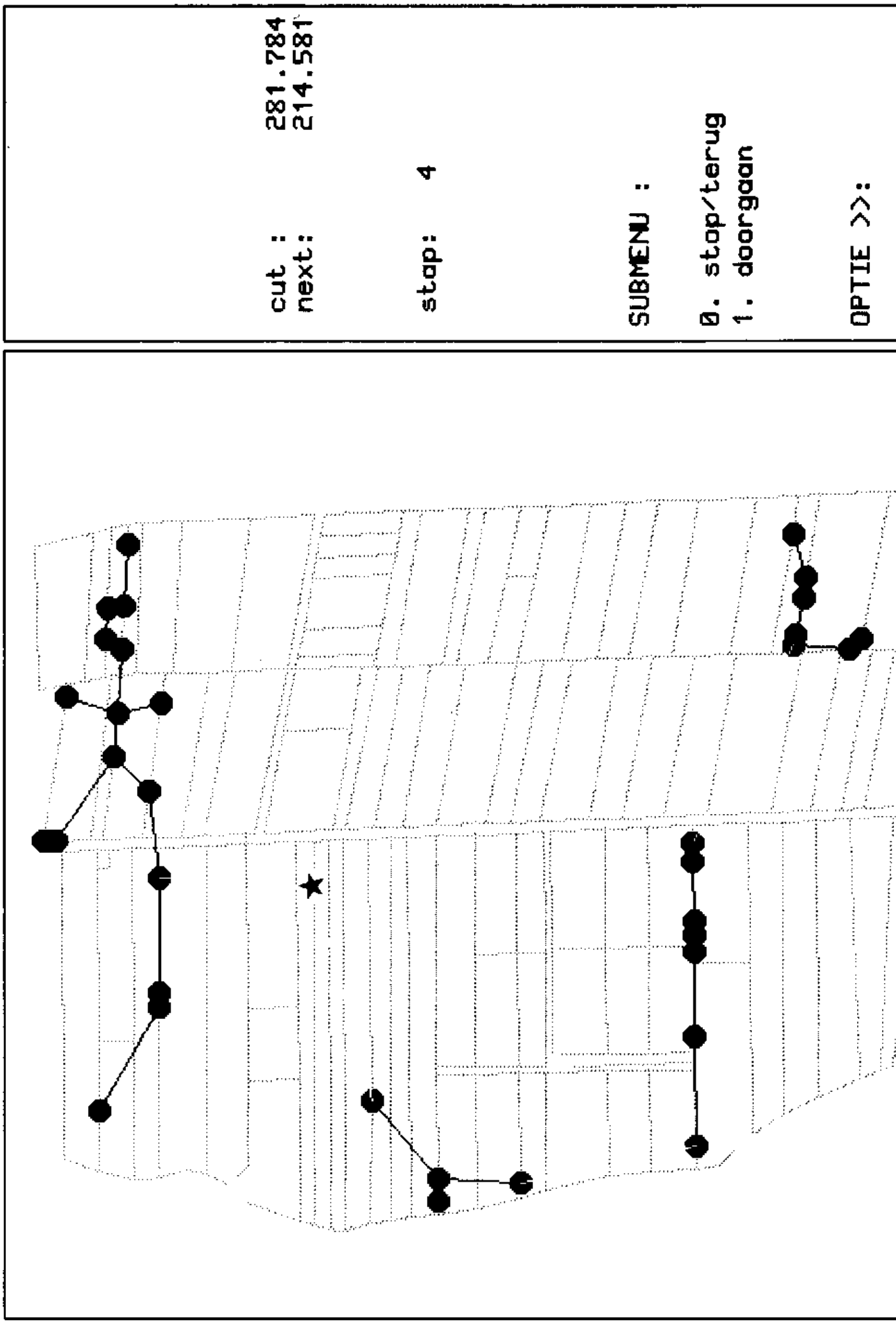


**Figure 5-3. Display of the eco-object most vulnerable for isolation. CENJAC in Binnenveld-area. ECONET1.**

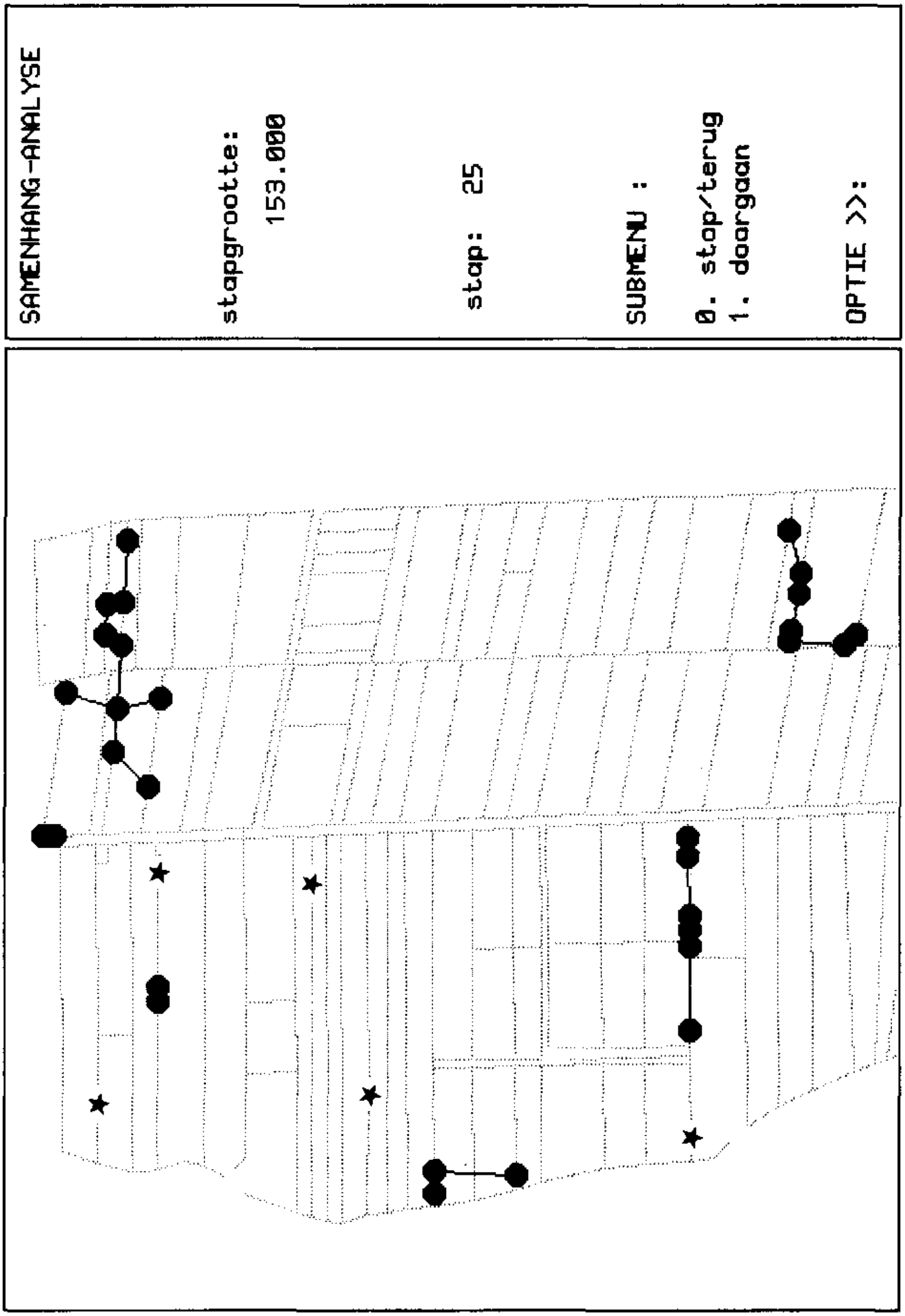


Figure 5-4. Display of coherence. CENJAC in Binnenveld-area. ECONET1.

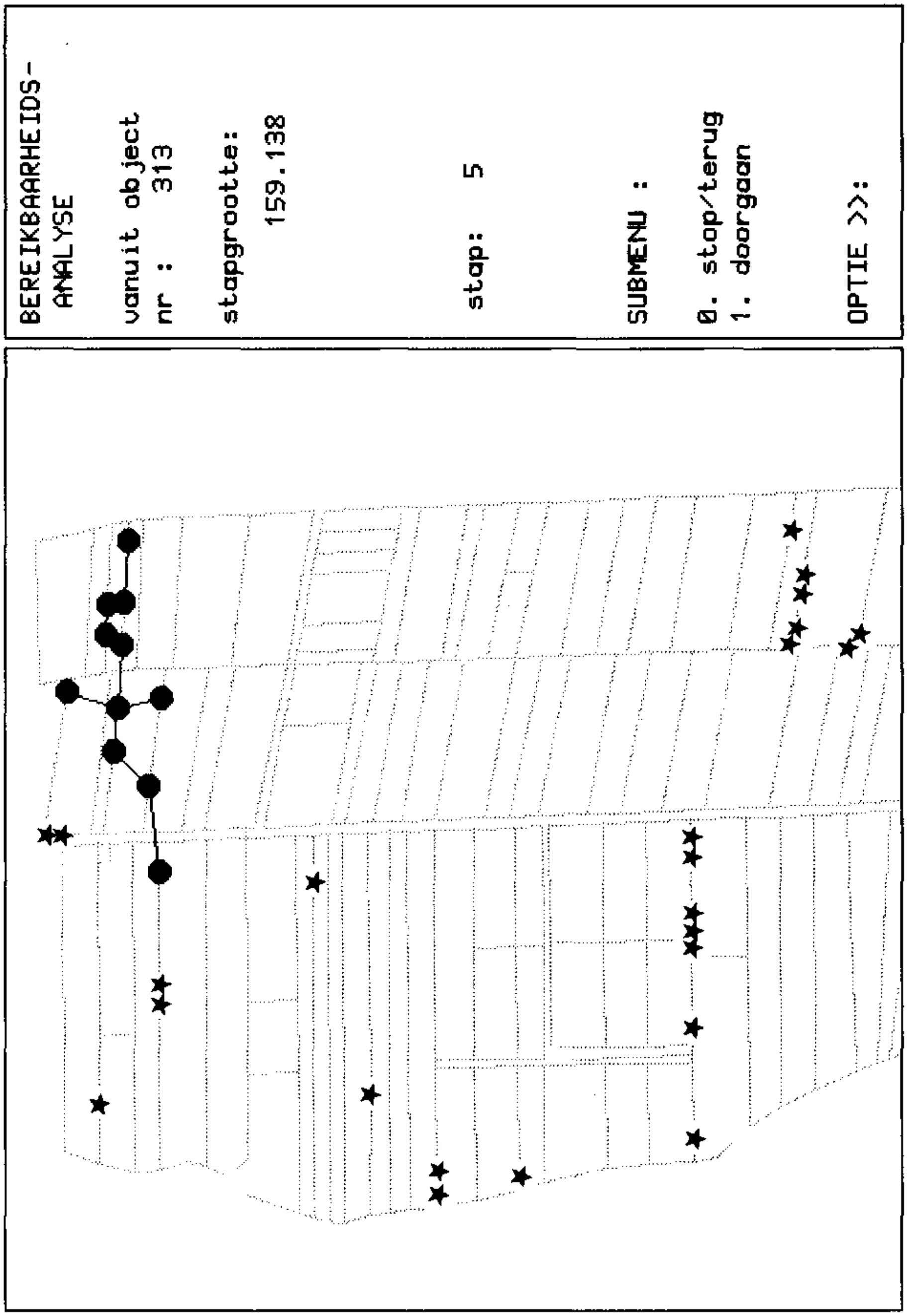


**Figure 5-5. Display of proximity. CENJAC in Binnenveld-area. ECONET1.**

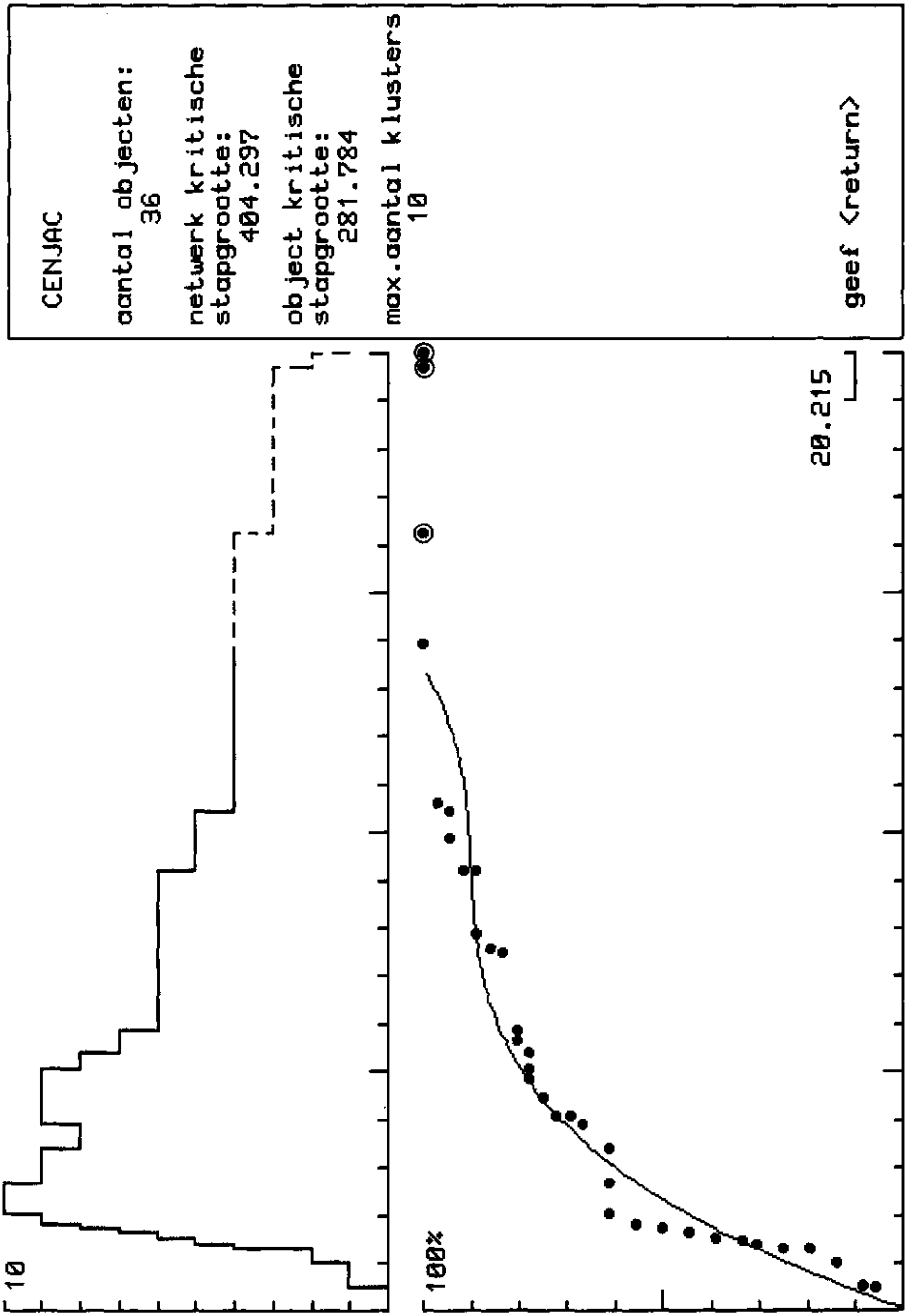


Figure 5-6. Display of some statistical data. CENJAC in Binnenveld-area. ECONET1.

## 5.5 ECONET2

**Model assumptions:**

a) It is assumed that ecological objects can only be reached along a pre-defined set of corridors.

b) It also is assumed that ecological objects can be spatially represented on a map by points or dots.

Figure 5-7 shows the same set of CENJAC-data used in figure 5-1, this time using the ditches as the pre-determined set of corridors along which the process of dispersion is executed. The result of ECONET2, in terms of ecological infrastructure, is also displayed in this figure.

ECONET2 is modelled like ECONET1, but for the determination of distances and routes in between eco-objects, use is made of INTRANET-procedures for distance and route calculation within networks. See chapter 4 for INTRANET-procedures.

**network friction**

It is imaginable that not all passways within the pre-determined set of corridors are equal in terms of dispersion-rate possible. Where ecologists can set such (relative) values to the various network-links of the corridor-system, use of such weights can be used for discrimination, as within INTRANET distances and routes calculated are based upon weighted Euclidean distances. Where no differentiation is known or attachable, weighting factors equalling 1 are to be used.

See figure 5-8 for a display of the most isolated eco-object when using ECONET2 on the data used in ECONET1.
Figure 5-9 displays the outcome when using the statistical feature of ECONET.

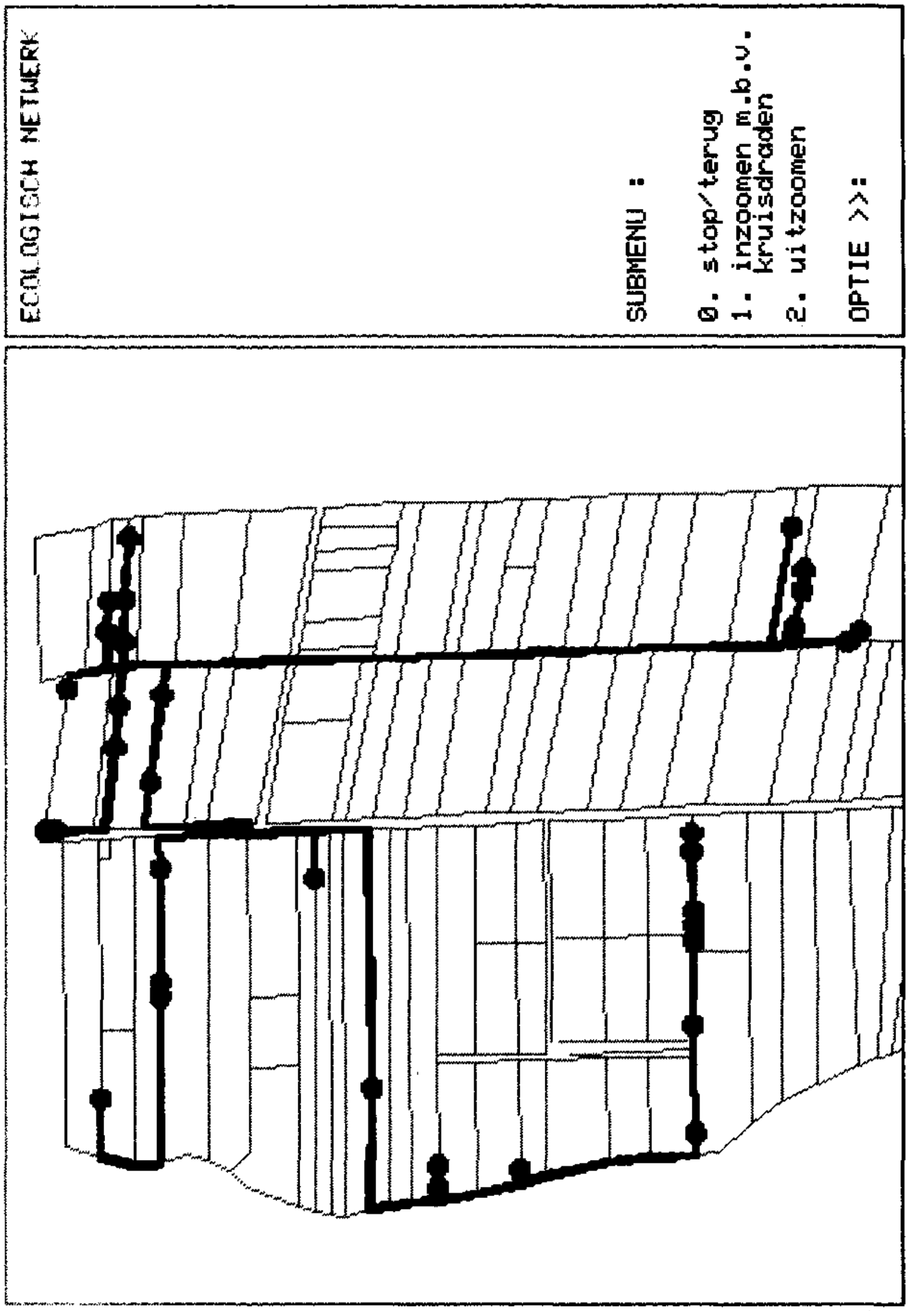


Figure 5-7. Display of the ecological infrastructure when using the ditch pattern as pre-determined network for dispersion. CENJAC in Binnenveld-area. ECONET2.

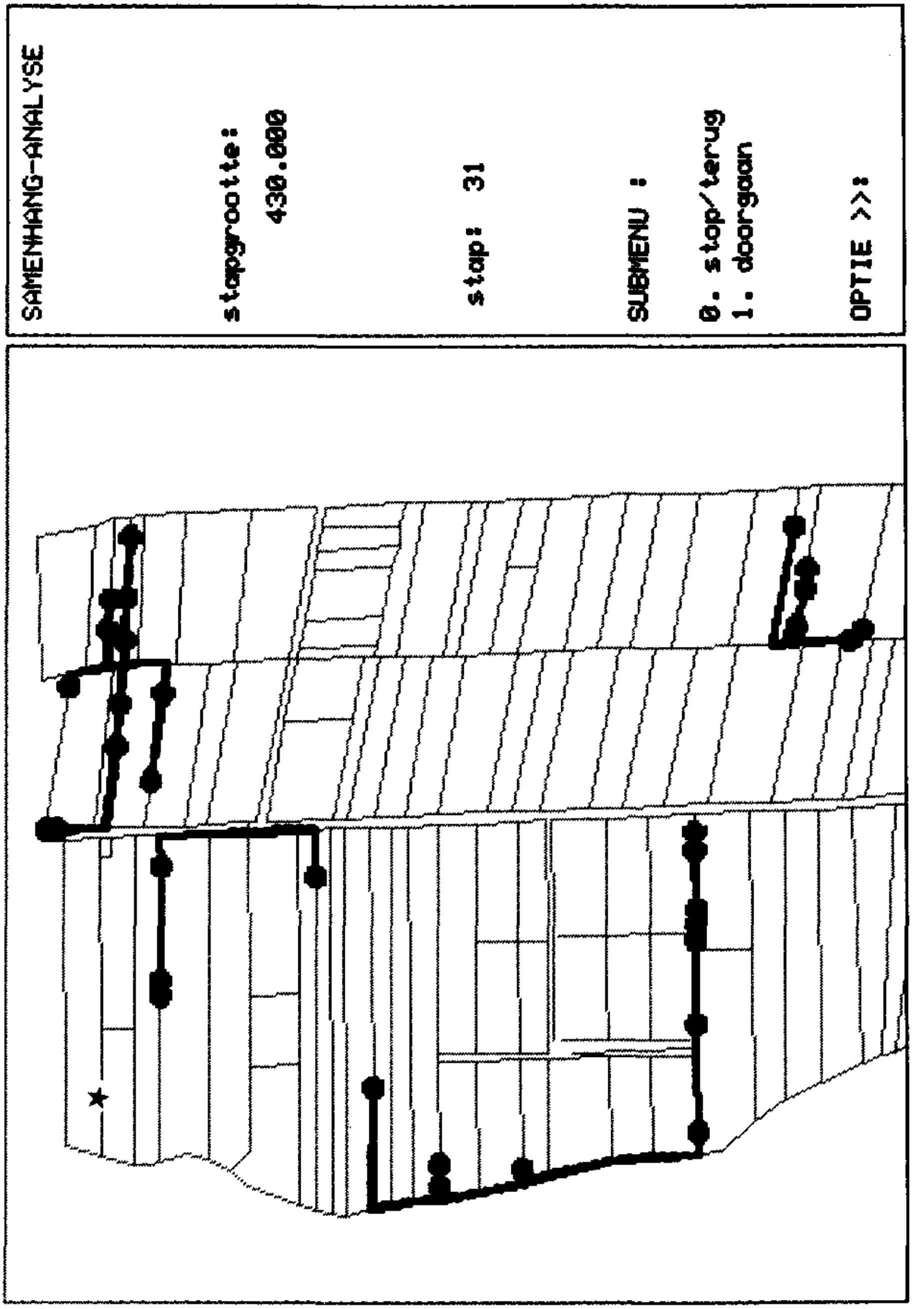


Figure 5-8. Output of ECONET2 showing the eco-object most easily isolated. CENJAC, Binnenveld-area.

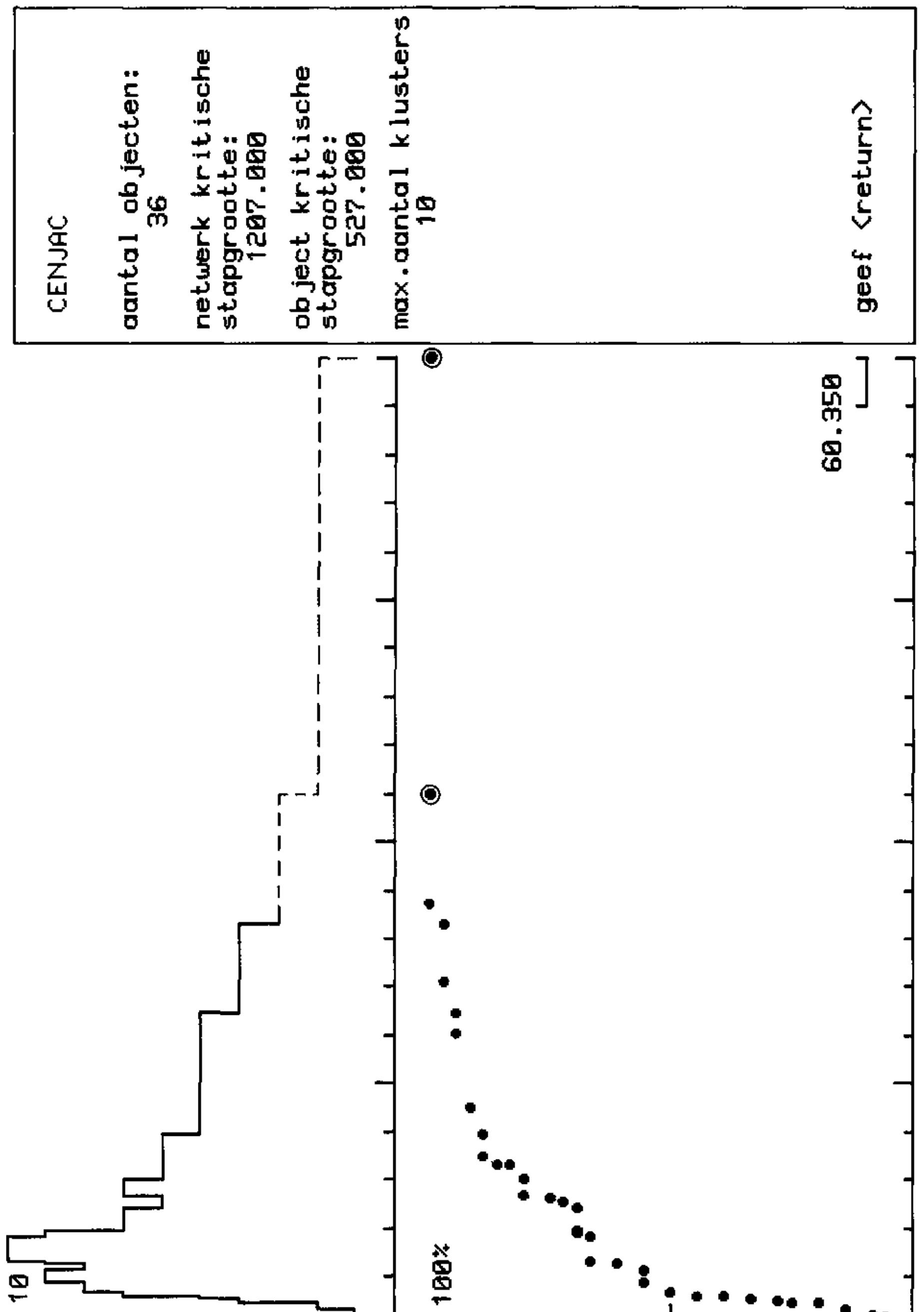


Figure 5-9. Display of statistical data of CENJAC, Binnenveld-area. ECONET2.

**Model interpretation and use for landuse planning**

Similar to ECONET1, ECONET2 can be used to trace the most important areas where dispersion is presumed to take place. Likewise, the more vulnerable objects can be located, and locations of meta-populations determined. Unlike ECONET1, however, ECONET2 makes use of a predetermined dispersion network. It locates the most important links within the given network and can be used to determine the effect of changes within and to the network. Landuse development plans can thus be developed along the findings.

## 5.6 ECONET3

**Model assumptions:**

A more sophisticated and complex approach towards ecological networks involves the modelling of real-life situations, taking into account size and form of eco-objects and those of obstacles in between.

The following assumptions are made:

a) It is assumed that the process of dispersion is a multi-lateral process; that is not along a pre-defined network.

b) It is assumed that ecological objects cannot be reached by crow-flight in those cases where flights are obstructed by areas defined as obstacles; where such obstructions are present, the shortest bypass will serve as a substitute; and,
areas defined as barriers are taken to be non-entry areas.

c) It is assumed that distances within ecological objects are disregarded; and,

d) It is assumed that eco-objects and bar-objects can be represented on a map by their 2-dimensional area configurations.

**Obstructions and distances**

Figure 5-10 shows a workbench example with 7 ecological objects (eco-objects) and 5 objects of resistance (bar-objects) within non-habitat areas.

Most direct routings between eco-objects are obstructed by the presence of bar-objects and such dispersion routes are taken to be invalid. With the help of the computer, valid routes can be determined.

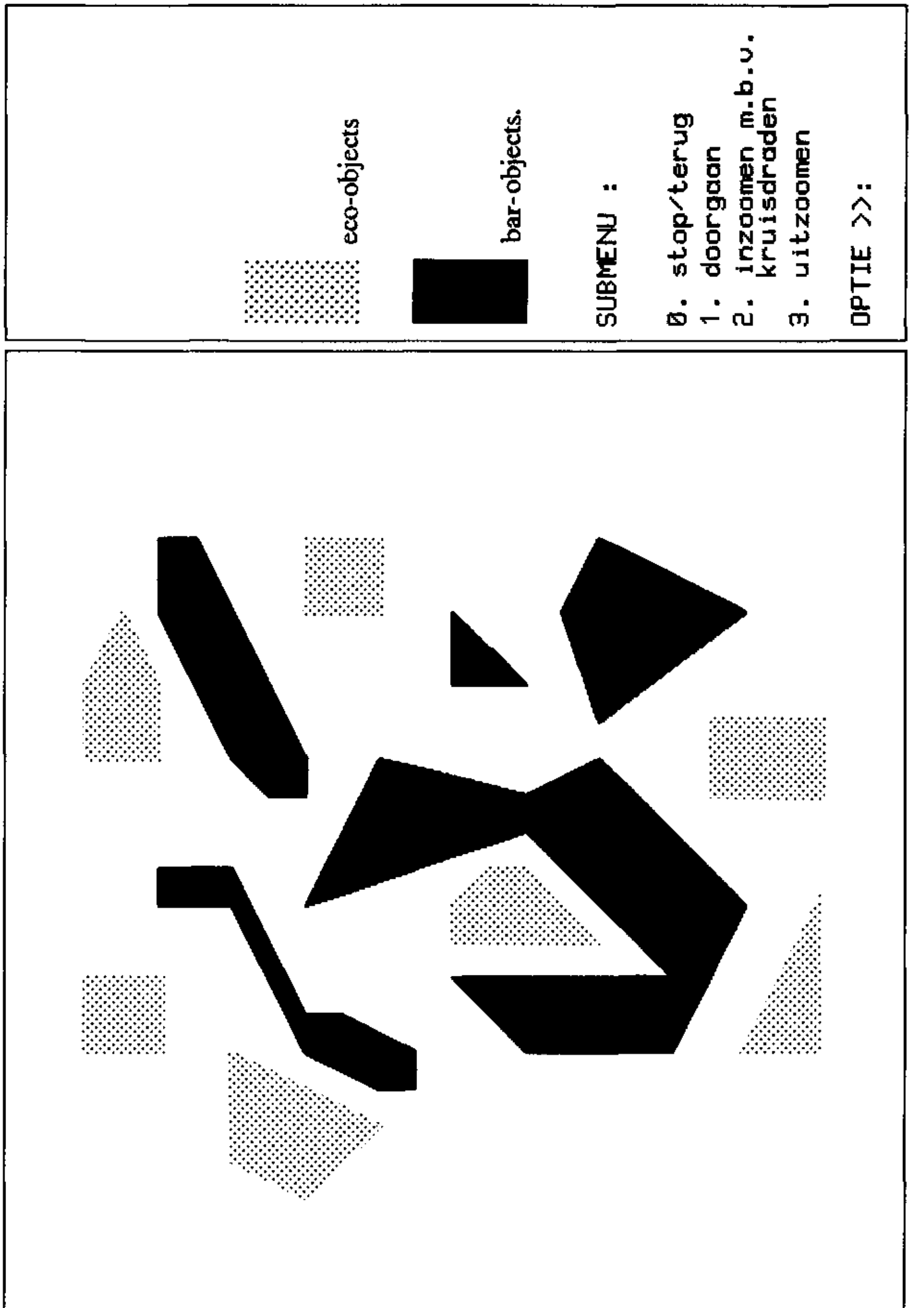


Figure 5-10. ECONET3. A workbench model with eco-objects and bar-objects.

The following procedure has been used to find the minimum spanning tree, that is, the ecological infrastructure:

a) create the total set of valid connections between all objects, whether eco-object or bar-object;
b) apply INTRANET-procedures (see chapter 4) on the created set of valid connections for calculating shortest distances and routes between eco-objects;
c) calculate the minimum spanning tree from the set of shortest connections as found in b)

Procedure a) not only involves the creation of connections between any two eco-objects, it also involves the creation of connections between eco-objects and bar-objects, as well as those between bar-objects and bar-objects.
See figure 5-11 for this network created, using the workbench data WOEST.
Procedure b) reduces the total set to the set with shortest distances between eco-objects. Procedure c) is similar to the one explained under ECONET1.

Barriers are taken into account by means of inserting bypasses into the set of direct connections. Direct-connections passing through barriers are left out. See Appendix 30 for more details on these procedures.

Once an eco-object has been reached, any sub-area within the eco-object is considered of equal value, and each place as ecologically safe (important) as the other. This means the ECONET3-model should disregard any distance between locations within an eco-object. Disregarding these distances causes a need for a reflection on the definition of remoteness of ecological objects and the use of distances. Whereas the value for remoteness in the simple model (ECONET1) was the mere sum of direct-distances between eco-objects, bypasses now have to be taken into account and zero-values introduced for distances within eco-objects.

From a mathematical point of view, this means that habitat-areas have to be regarded as node-objects as in ECONET1.
Within ECONET3 this step has been achieved by substituting the set of polygons representing the eco-objects with a set of dummy-nodes -- each one representing one complete eco-object -- at the same time the calculated dis-

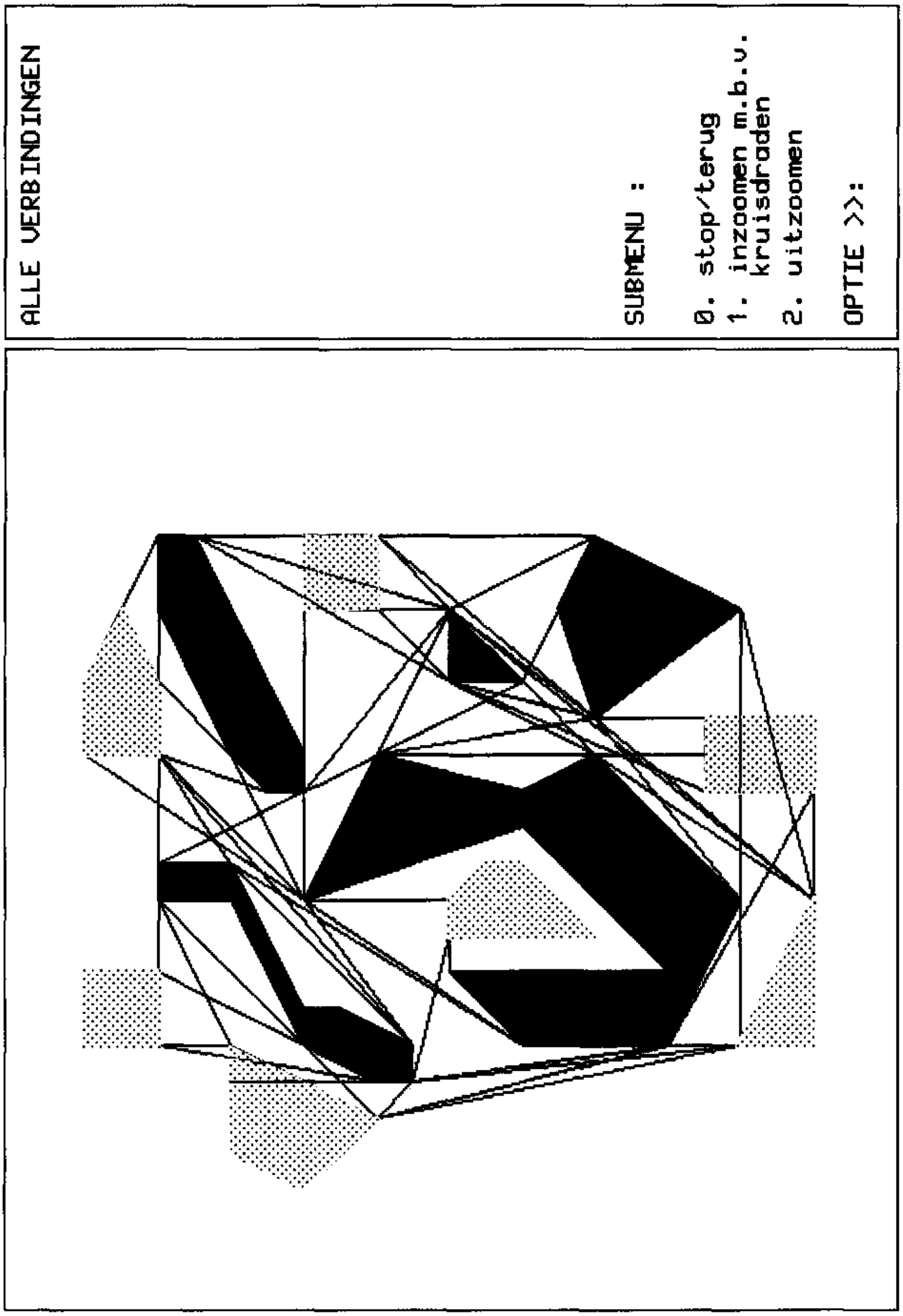


**Figure 5-11. ECONET3. The complete network of valid connections between eco- and bar-objects.**

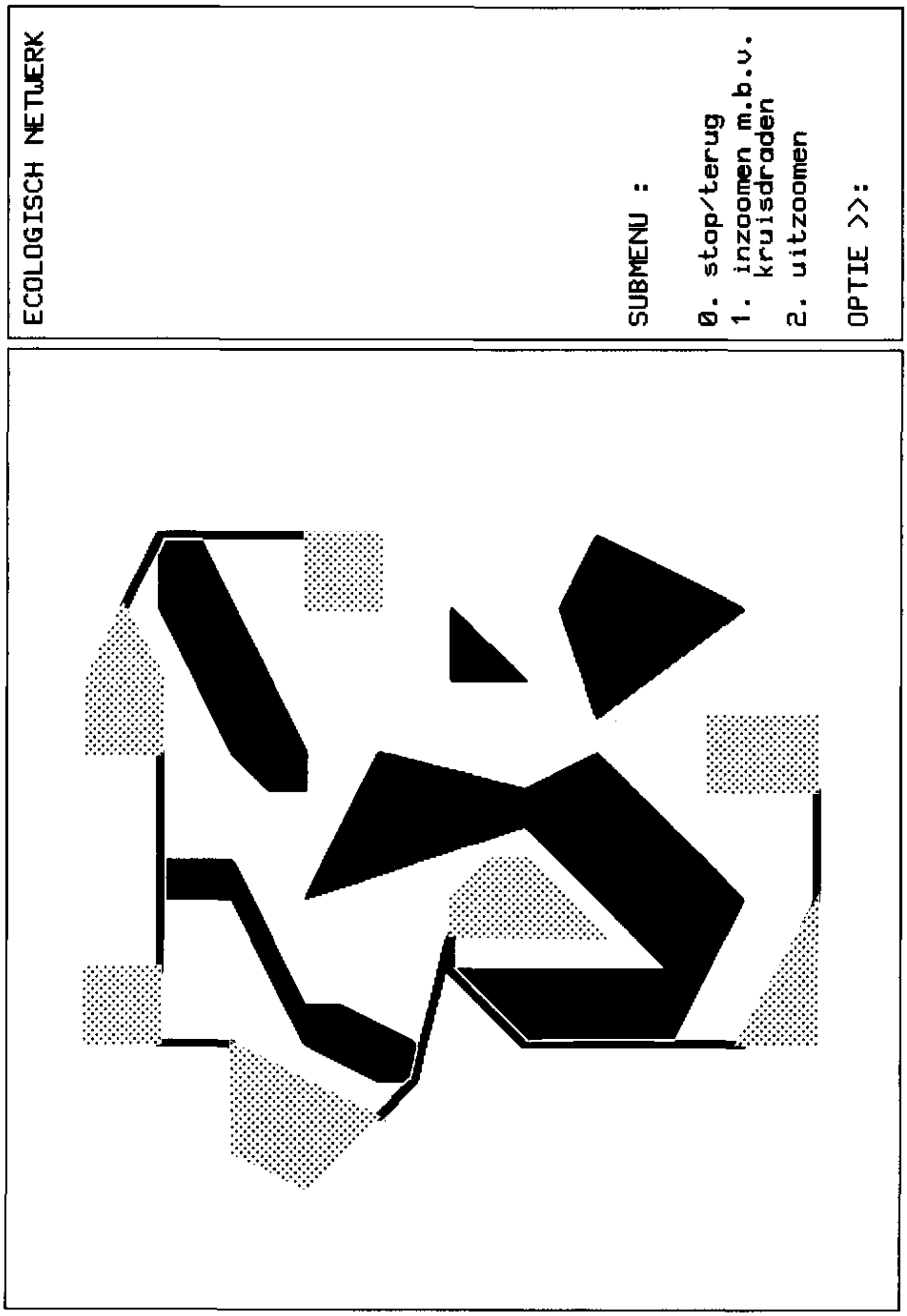


Figure 5-12. ECONET3. Display of the ecological infrastructure.

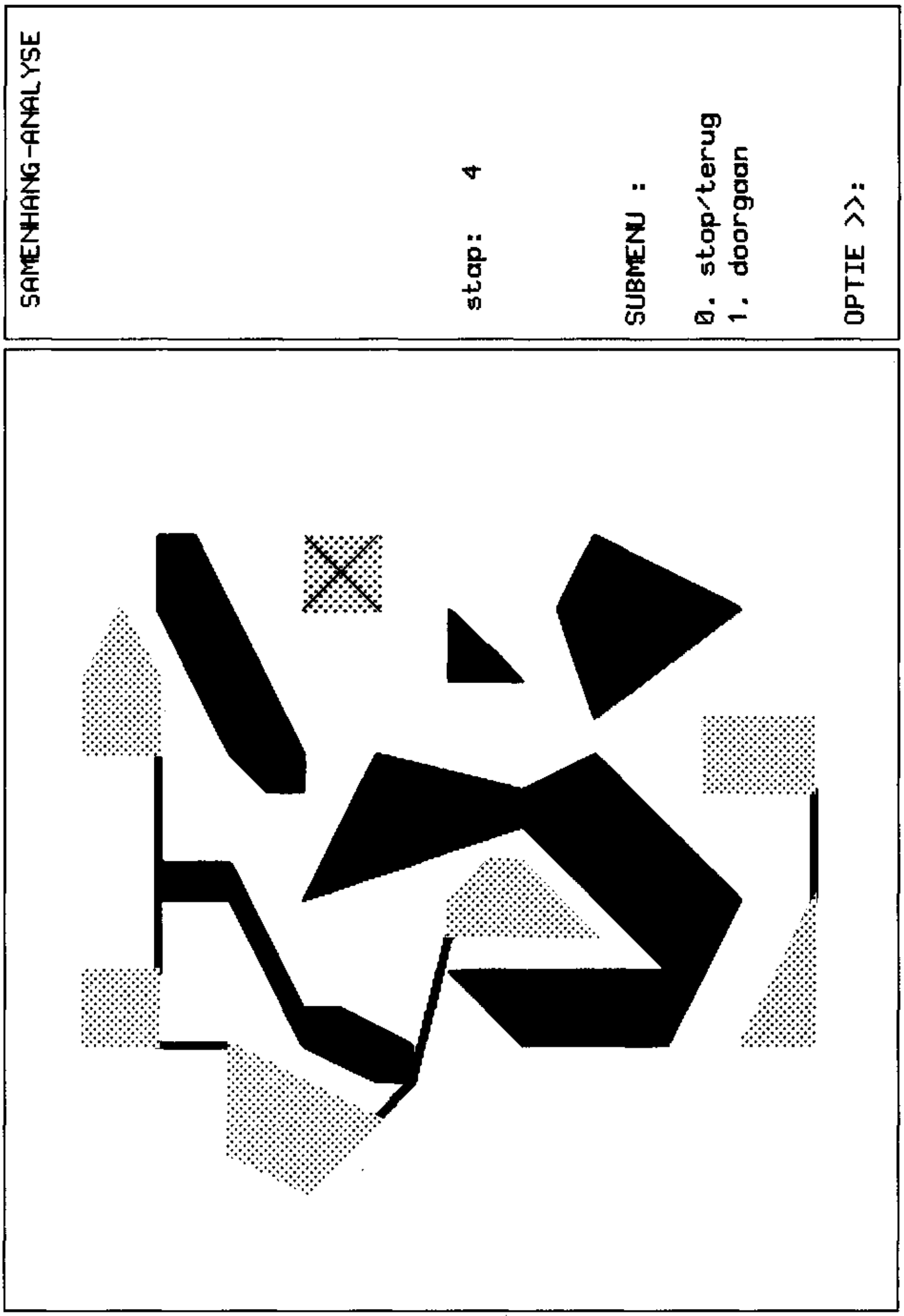


Figure 5-13. ECONET3-output showing the eco-object most easily isolated.

tances of valid connections between eco-objects are maintained as calculated in the procedures a, b, and c, mentioned above.
See figures 5-11 and 5-13, both output of ECONET3 on data WOEST.

## 5.7 SOME OPERATIONAL ASPECTS

### The interactive use of ECONET

ECONET has been created as a set of fully menu-driven color-graphic computer (packages) for calculating and displaying ecological relationships in respect to location of habitat-areas. It is a fully operational tool for landuse planners, and it is fitted with alpha-numeric and graphic editing tools for interactive use. Thus, within a creative planning setting, the updating of location and size of ecological objects and obstacles can quickly be done and their impact calculated and displayed.
The programs prompt questions relating to coherence and proximity of spatially scattered habitat-areas. The ECONET3 model fully incorporates and discounts barriers between ecological objects.
ECONET is fully menu-driven and its graphic output is based on vector-image building to allow maximum readability. Zoom functions allow detailed mapping.
Because of these menus only little knowledge is needed of how ECONET operates on the technical/operational level.

ECONET can be used for grading plan-situations as a result of other programs, or it can be used more actively. The programs display the ecological infrastructure, show what eco-objects are weakest from the viewpoint of remoteness, and what impact can be expected at what time. ECONET also can serve as an active tool for finding boundary-conditions for other landuse forms.

### Types of output

Output can be generated in various forms, according to the workings of the various menu-options. Zoom-functions allow the creation of overview and close-up detailed information, while hard-copy output allows for a mapping on paper or on overhead sheet.

**Menus in general**

ECONET has been fitted with menu options which easily lead the user through all features. Once ECONET has been started the user gets a main-menu from which to choose. Selection then leads to a follow-up menu where again one must choose. In this way, a complete hierarchy is obtained and the program-user has to find his/her way within it.

**Input requirements**

The ECONET programs can operate only when the user has coordinate information on ecological objects and obstacles. ECONET has not been fitted with map-digitizing options, so (x,y) coordinates of the polygons representing the boundary of objects have to be gathered by other means.
In preparation for using the model, it is necessary to:

- number the eco-objects (respective bar-obstacles if present) and to
- assemble the series of coordinates of the boundaries of these objects, as far as form and size are concerned; otherwise a representative (x,y) value for the location of the object is necessary.

**Hardware/software**

ECONET has been written in FORTRAN/77 using VAX/VMS. The GKS-UNIRAS toolbox of European Software Contractors is used for the graphic part. ECONET operates on TEK42xx terminals.

## 5.8 SUMMARY AND CONCLUSIONS

Because nature is under pressure and areas with natural conditions are rapidly diminishing, it is necessary to increase ecological knowledge within landuse planning procedures.
With ECONET, dispersion routes of species can be modelled by means of tracing the location of the minimum spanning tree of connections between habitat-areas within non-habitat areas.
In cases where the dispersion process is known to exist only within a specific corridor system, this network has to be defined in order to limit the model-flow within that area only.

Taking size and form of ecological objects and those of dispersion obstructions into consideration, modelling the dispersion process becomes more complicated because bypasses have to be found.
With the ECONET programs, the location of the ecological infrastructure and the most easily isolated habitat areas can be determined and displayed, thus upgrading insight into the ecological values of land within development projects.
With ECONET the ecological interpretation of the location of habitat-areas, and their relationship, is based on the parameter distance only.
Where (approximations of) dispersion rates of species are known, the clusters of habitat-areas forming the meta-populations can be displayed.
ECONET can be used interactively, allowing planners to deal with what-if questions.

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# 6. A SYNOPTIC REVIEW

## 6.1 THE PROGRAMS IN CONTEXT

With the tools described in the preceding chapters, contributions can be made towards solving certain spatial planning questions pertaining to a sustainable development. Among them are those questions formulated within landuse planning and aimed at conceiving specific strategies and designs.
The concept of land as an interrelated complex of abiotic, biotic and anthropogenic sub-systems allows the setting of planning strategies, not only in specific cases for individuals and specific landuse, but also in multi-sectoral context involving public planning on larger scales. See also figure 6.1.

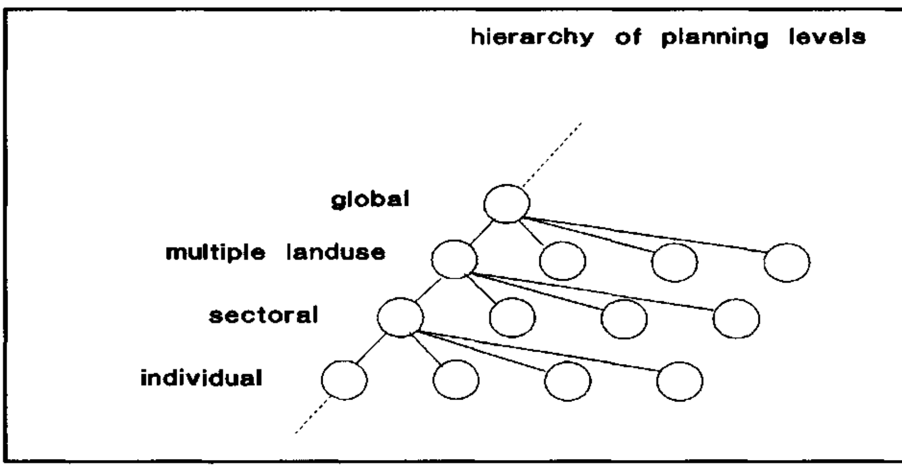


Figure 6.1. Landuse planning levels in terms of related landuse questions.

Tools for helping to solve non-singular landuse questions, are to be used in their mutual context (see figure 2-5), and used in the framework indicated in figure 6.2 (note: this a specification of figure 2-10 of chapter 2).
With land seen as the corporate planning object and landuse questions seen as interrelated problems, the contributions to the toolkit of landuse planners by the introduction of AKCI, INTRANET and ECONET, have to be seen within such a corporate context.
AKCI contributes to understanding present landuse. It has features for the interpretation and display of locations of areas with, for example, poor land-

conditions. Having thus pinpointed areas where landuse and landconditions are unfavorable, plans can then be developed to overcome such situations by mitigating the related problems as much as possible.
With INTRANET a better understanding of the value of the (road)infrastructure layout is possible. The effect of design-proposals and change introduced can be tested in terms of travel distances and time involved. Several features of INTRANET allow a 'best positioning' of activities within the area to be redeveloped, thus contributing to answering the basic design question, "where to have and do what".
The impact of (a shift in) landuse from an ecological point of view can be tested with ECONET and used for incentives to choose between various landunits to be (re)developed.

The approach of landuse units as an interrelated complex, requires an optimization not only for landuse within singular-landuse units, but also on higher performance levels, involving sectoral and multi-sectoral organizational levels. This approach calls for an optimization of the interrelations between the various landuses. Effects of the various landuses on one another are to be taken into account.
A simultaneous use of the modelling and planning programs, using the calculation results of the one as input for the other, contributes to a better understanding of various processes in their spatial and mutual context.

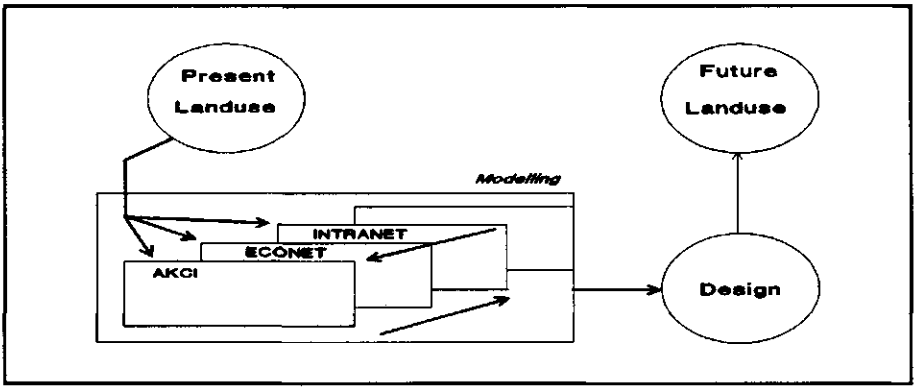


Figure 6-2. Modelling with AKCI, INTRANET and ECONET.

To avoid a possible misunderstanding, it is to be understood that the three

programs developed in this study and shown in figure 6-2, are to be seen as supplementary to other programs in the general toolkit.
For an overview of the principles, the primary use, some constraints, and the realm of the three programs, see Table 6-1.

Table 6-1. Characteristics of AKCI, INTRANET and ECONET

| program | principle | primary use | constraints |
|---|---|---|---|
| AKCI | boolean mapping of entities within the data-base | display of present landuse according to attributes of entities | presence of C.I. data-files with socio-economic and topographic data of entities |
| | goals | realm | examples |
| | insight into locations and interrelations of landuse, for example for purposes of trade off | primarily for agriculture land-use in non-virgin areas | . distance of land relative to the holding<br>. land in use by farmer F |
| INTRANET | calculation of distances between nodes in a network | determination of distance values for purposes of (economic) evaluation for optimization of accessibility of landuse, layout and use of (road)infrastructures | digitized data of the infrastructure |
| | goals | realm | examples |
| | optimization of landuses and infrastructure system | any infrastructure system, for example: rural roadsystems, canal systems, railroads, electricity networks | . determination of locations for public facilities<br>. minimizing travel demand |
| ECONET | determination of minimum spanning tree and spatial interrelations between the nodes within the spanning tree | determination of spatial network along which dispersion of genetic (plant and animal) material flows; determination of vulnerability of niches due to isolation | digitized data of entities; (indications of) dispersion characteristics of species |
| | goals | realm | examples |
| | optimization of landuses in ecological context | regions with scattered areas highly valued for their ecological values | . determination of corridor system<br>. determination of vulnerable niches |

Aside from the program AKCI, for which much and more data has to be registered, the programs are basically in need only of the topographic information, that is, the coordinate (x,y) data of the entities involved. By means of digitizing equipment, infrastructures, like the rural road systems, can be fairly easily captured in sets with series of link-coordinates. Such equipment, by similar use, can also be used to create the input-data necessary for the ecological models.

## 6.2 SOME LIMITATIONS AND POSSIBLE COURSES FOR ACTION

As stated, present landuse and related conditions have to be placed in a context of sustainable development, the latter referring to the question how to cope with future situations and demands. This means landuse has to be evaluated in a continuous setting rather than being restricted to look at characteristics of accidental, discrete moments in time.
AKCI does not allow the showing of landuse over time. Above that, it is restricted in showing agricultural landuse only. Apart from this sectoral quality, if one were to have a series of sets over time, the dynamics of the farming of land perhaps could be captured and understood much better. In view of such a perception, the limitation of data to the present number of social and economic indicators will also have to be lifted. For this one might not only think in the direction of having to add more managerial data concerning the production processes, including more data on the agribusiness[1], but also towards including more abiotic and biotic data on which such agricultural production is based.
Presently, there is no feature for overlaying data from sources available outside the AKCI-database. To interrelate information existing within other databases, such a feature should be investigated.

One of INTRANET's limitations is the difficulty of giving weight to the various impedance factors, that is, the weighing attribute for each link of the network.

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1 Reference is made to agricultural industry supplying the primary farming industry as well as the agricultural industry using the farm-output for further processing.

As far as travel is concerned, various modes of travel will have different preferences for weights. Which weights are to be used is a normative question. Presently, to overcome such assignment difficulties, various sets of weights can be given and the results of the calculations compared.
INTRANET has been made to cope with two-way travel within networks. Obviously there is a need to devise a model with similar features, but for one-way travel networks. This INTRANET variant has not yet been put together.
Research into the introduction of heuristics, as far as the travelling salesman problems are concerned, can lead to performance improvement and additional features.
As far as ECONET is concerned, calculations for infrastructure display are solely based on the parameter distance. Weights given to distance are presently purely linear and no influence of population size as a result of locational suitability (as a result of the size of an eco-object) is taken into consideration.
Presently, barriers are taken to be absolute, while some permeability should be allowed for. More research is needed to find ways to incorporate permeable barriers. In fact, more research is needed to introduce stochastic population dynamics into the model. Many characteristics of species, populations, and ecosystems, unfortunately are still unknown, thus complicating the modelling.

With INTRANET and ECONET, contributions towards necessary impact analysis of landuse plans and to the planning of new landuse situations have been given. The question arises whether the toolkit of landuse planners can be expanded even further. One expansion foreseen, is the one in which there is an optimization model for the relocation of the farmland (and thus also of that of the agricultural landuse) within areas indicated by physical planning for farming. Here, reference is made to ongoing research[2] concerning a linear programming model, in which three spatial parameters are to be optimized (see also chapter 3):
- the number of landuse units per agriculture holding
- the distance to be travelled between the landuse units
- the amount of land needed near the farm buildings.

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Reference is made to AMRA, Allocation Model for Rural Areas, a linear programming complex using SCICONIC-LP software.

In conjunction with the use of ECONET and INTRANET, then an even further extended type of impact analysis and design of landuse plans is possible, within the realm of land development and physical planning.

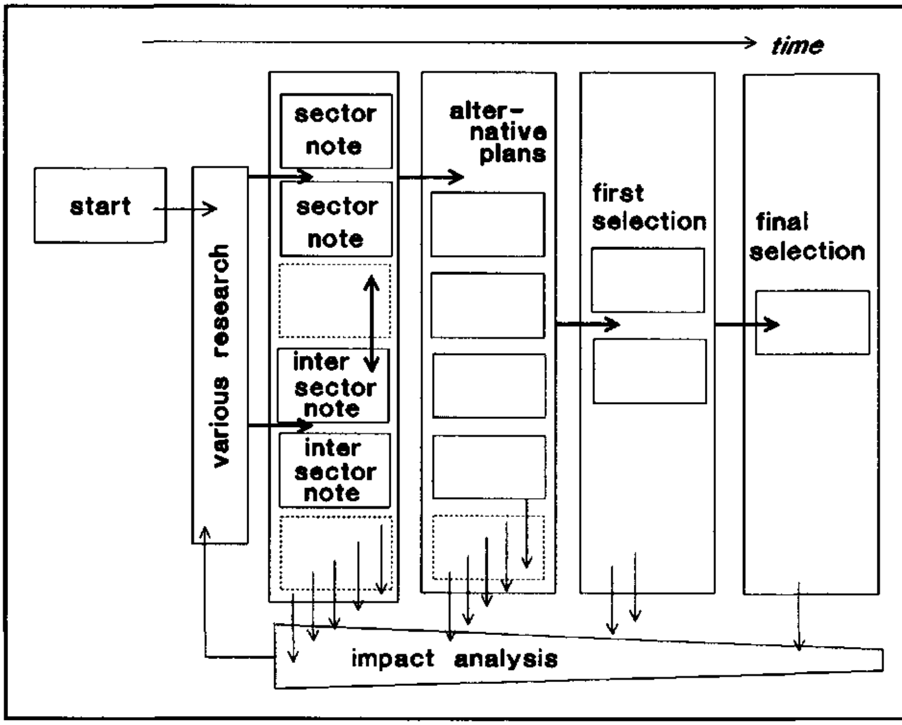


Figure 6-3. An extended plan-design procedure.

Figure 6-3 depicts such a situation (note: this figure is an adaption of figure 2-12). It indicates that the number of sector-notes has to be increased relative to the number of major landuses. It also indicates inter-sector notes dealing with the inter-relationships between the various landuses have to be made.
Sector-notes no longer are to be written from a viewpoint land-development has to be claimed on a sector-basis, but from the viewpoint of having to contribute to the total welfare. Ideally, there should be a work-relationship with the research phase, in the sense that models are to be built, explaining the various sector-processes and their output as related to input and parameters set.
Model-analysis and impact-analysis have to be executed, leading up to the

creation of a final plan, or to that of a set of good alternatives from which the parties concerned are to choose.

With the above indicated present limitations of the programs, an indication is given of the direction in which research can continue as far as spatial analysis of landuse and planning for infrastructures and landuse is concerned.
Some shortcomings have been sighted, and can be overcome by fitting together technical know-how already present. Others, somewhat more difficult to overcome, are those more related to actual shortcomings in know-how.

The interactive programs developed, indicate that interactive modelling and monitoring for multiple-landuse planning, is a workable route for perceiving a good internal representation of the land-development problem. It is a workable route, along which designs for future situations can developed.
It is my belief, that such a planning methodology represents a feasible route for the reduction of the problem-distance in favor of reaching more sustainable landuse. Proof for such, however, is absent; an even more complex interpretation of land, than given in this study, would be necessary.

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**Jurgens, C.R., 1992**
**Tools for the spatial analysis of land and for the planning of infrastructures in multiple-landuse situations.**

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**Gereedschap voor de ruimtelijke analyse van land en voor het ontwerpen van infrastructuren bij meervoudig grondgebruik.**

## SAMENVATTING

De planvorming met betrekking tot de inrichting van land omvat de activiteiten planologie, landinrichting en beheer en raakt zowel het individu als het collectief. Land, het object van de bovengenoemde planvorming, wordt gezien als een samenhangend stelsel complexen waarin te onderscheiden zijn processen van abiotische-, biotische- en antropogene aard. Het doel van de planvorming dient gericht te zijn op het verkrijgen van duurzaam landgebruik. Ter verwezenlijking hiervan, dient men in de planvorming gebruik te maken van methoden en technieken die primair gericht zijn op het optimaliseren van meervoudige doelstellingen.

De mogelijkheden tot sturing door de mens van de bovengenoemde processen zijn beperkt, maar dienen gezien te worden vanuit het concept dat de werkelijkheid cybernetische eigenschappen heeft. De mens komt kennis te kort ten aanzien van het werkelijk functioneren van de genoemde complexen. Dit veroorzaakt onzekerheden ten aanzien van mogelijkheden tot sturing en vraagt meer kennis en onderzoek met betrekking tot oorzaak - gevolg relaties.
Het verrichten van onderzoek en het modelleren van de werkelijkheid naar gevonden data, levert een werkproces waarbinnen het mogelijk is inschattingen te maken van de effecten van planvoorstellen, mits gebruik gemaakt wordt van gevoeligheidanalyses met een zogenaamde terugkoppeling. Door het volgen van een dergelijke cyclische werkwijze wordt men in staat gesteld ontwerpvoorstellen te ontwikkelen die het verwezenlijken waard zijn.

Het onderzoek heeft zich gericht op planvorming rondom vormgevingsfactoren waarbij de ruimtelijke ligging van objecten van essentieel belang is. Dit heeft geresulteerd in computerprogrammatuur te gebruiken als hulpmiddel in de ruimtelijke planvorming.
De programmatuur heeft de volgende naamgeving heeft gekregen: AKCI,

respectievelijk INTRANET en ECONET.

AKCI is het acroniem voor *"Automatische Kartografie van de Cultuurtechnische Inventarisatie"*. De data-bestanden, C.I. geheten, zijn bestanden die gebruikt worden in de planvorming zoals deze plaats vindt bij de Landinrichtingsdienst. De bestanden omvatten data met betrekking tot agrarische bedrijven in landinrichtingsgebieden en wel op het terrein van de sociaal-economische gegevens en die met betrekking tot grondgebruik en topografie van kavels in gebruik bij de voornoemde bedrijven.
De gebruiksmogelijkheden van de data-bestanden zijn door het ontwikkelde programma AKCI verruimd. Het programma maakt visuele inspectie van de landinrichtingsgebieden mogelijk, door het op beeldscherm tonen van interactief aan te maken thematische kaarten. Alfa-numerieke data van kavels en van bedrijven zijn, na aanduiding van de objecten door cursor-besturing, terzijde van de op scherm vertoonde kaarten, te verkrijgen.

INTRANET is het resultaat van het samenstellen van een groot aantal modules die zich richten op *INTeractieve Route Analyse in NETwerken.*
Met netwerken wordt geduid op verbindingenstelsels, waaronder bijvoorbeeld wegenstelsels.
Route-vraagstukken kunnen opgevat worden als basisvraagstukken voor menig planologisch-, inrichtings- en beheersvraagstuk. Deze richten zich behalve op het vinden van optimale routekeuzes ook op zaken als toegankelijkheid en bereikbaarheid van land, alsook op dat van wenselijke locatie van grondgebruik. Het (onsluitings)stelsel, de ligging en de mate van voorkomen alsook de kwaliteit van de verbindingen bepaalt mede de betekenis van het ontsloten land en de activiteiten die daar op plaats vinden.
Verbindingenstelsels zijn wiskundig voor te stellen door middel van een netwerk van punten en verbindingen daartussen. Afstand- en routeberekening vormen een rekenprobleem in geval er sprake is van een netwerk met veel punten en verbindingen. Met INTRANET zijn er werkwijzen gevonden om dit rekenprobleem te reduceren. Hierdoor is er interactief te gebruiken gereedschap ontstaan voor analyse en planvorming in landinrichtings- en beheersverband. Met de programmatuur is het mogelijk om afstanden en te volgen routes snel te berekenen. Ook andere planningsvraagstukken, zoals die met betrekking tot de bepaling van bereikbaarheid van objecten, doorgaande route bepaling bij een ingewikkelder reisplan, alsook die in combinatie met werk-

planvraagstukken, kunnen worden beantwoord. Door INTRANET te gebruiken als interactief instrument voor de bepaling van de effecten van planvoorstellen, wordt een bijdrage geleverd in het vinden van het betere plan.

ECONET is ontwikkelde programmatuur gericht op vergroting van het gebruik van ecologisch belangrijke data in de ruimtelijke planvorming, met name die met betrekking tot wat kan worden genoemd de *ECOlogische NETwerken.*
Omdat er alom sprake is van vergaande aantastingen van de natuur, is het belangrijk om in de ruimtelijke planvorming meer gebruik te maken van kennis met betrekking tot ecologische processen, waaronder die welke plaatsvinden tussen ruimtelijk gespreid liggende gebieden met veel natuurwaarden.
Met ECONET is aan de ligging van dergelijke gebieden betekenis te geven op basis van onderlinge afstand en bereikbaarheid. De belangrijkste verbindingenstelsels waarlangs genetische dispersie en -uitwisseling tussen dergelijke gebieden met grote ecologische betekenis tot stand komt, kunnen met ECONET worden bepaald door het berekenen van de zogenaamde "minimum spanning tree".
Indien dispersie plaatsvindt in een "bekende" deel-ruimte, bijvoorbeeld in een stelsel van sloten, dient een dergelijke ruimte als verbindingenstelsel vooraf te worden bepaald en ingevoerd, teneinde het dispersie-proces tot die ruimte te beperken (ECONET2).
Daar waar het belangrijk is behalve de locatie van de ecologisch belangrijke gebieden ook vorm en grootte mee te laten doen, alsook die van dispersieblokkerende barrières, is de modellering van de werkelijkheid complex. Indirecte verbindingen tussen de objecten dienen dan te worden bepaald alvorens het ecologische netwerk kan worden vastgesteld (ECONET3).
Met de ECONET programmatuur is het mogelijk de rangorde van kwetsbaarheid van habitat-gebieden te bepalen, waardoor meer inzicht ontstaat in de locatie-betekenis van gebiedsdelen.
Daar waar kennis voorhanden is met betrekking tot dispersie-snelheden (afstanden per tijdseenheid) van plant- en diersoorten, kan de locatie van metapopulaties in-de-tijd worden gevisualiseerd.
ECONET kan interactief worden gebruikt en biedt aldus mogelijkheden om planvoorstellen op effecten door te rekenen en te komen tot het betere plan.

## CURRICULUM VITAE

Clifford Roelof Jurgens was born in 1944 in Assen, the Netherlands.
In this city, in 1962, he finished secondary school (RHBS) and received a scholarship to attend Bentley High School in Livonia (Michigan, USA).
The following year he enrolled the Agricultural University in Wageningen, the Netherlands, where in 1970 he majored in agrohydrology with minors in economics, mathematics and irrigation techniques. Partly based on experiences during his practical term in Surinam in 1969, he decided to start his career with the Food and Agriculture Organization. For two years he has been employed as a farmmanagement economist in a Groundwater Development Project in the desert regions of Jordan, after which he became head of the irrigation section of a FAO horticulture and irrigation project in Zambia.
In 1975 he had a short term employment with the Agricultural University in Wageningen, after which followed a feasibility study for the German bilateral aid service to Haute Volta (presently Bourkina Faso).
He then joined the Dutch Government Service for Land and Water Use, presently called Landinrichtingsdienst, and worked for three years for the research section of this Service in the province of Gelderland. After this he was stationed for three years at the headquarters of this Service, and among others has been engaged in the use of the data-files called "Cultuurtechnische Inventarisatie" and in the development of computerprograms directed at the optimization of re-allotment in development areas.
In 1981 he joined the department of Land and Water Use[1] of the University in Wageningen, where he teaches in landuse planning.
His research is in the field of the use of computers in landuse planning.
With a group of like-minded he stood at the dawn of the University Centre for Geographic Information (CGI), presently the heart of the university for remote sensing and geographic information systems.
He represents the department of Physical Planning and Rural Development within the sector board of the faculty.

1 The department has joined landscape architects and physical planners into a newly formed department called Physical Planning and Rural Development.

## LIST OF APPENDICES

**Figures in Appendices.**



**Tables in Appendices.**

**ATTRIBUTE CONTENTS OF C.I.** **APPENDIX 1**

<u>Attributes monitored on farm level</u>
dorpsbehorennummer van de bedrijfsgebouwen
gemeentenummer van de gebruiker
gebruikersnummer binnen de gemeente
naam
adres
postcode
woonplaats
aantal bedrijfshoofden
geboortejaar bedrijfshoofd
aantal meewerkende zoons
aantal vreemde arbeidskrachten
oppervlakte bouwland gemeten in are
oppervlakte grasland gemeten in aren
oppervlakte van de huiskavel
oppervlakte van de huisbedrijfskavel
bedrijfsgroote in are (CBS)
oppervlakte gepacht in are
ligging van de bedrijfsgebouwen binnen een dorpskom
x-coordinaat (km) bedrijfsgebouwen
x-coordinaat (m) idem
y-coordinaat (km) idem
y-coordinaat (m) idem
gemiddelde afstand van de grond tot het centrum van de bedrijfsgebouwen via verharde weg in hm
idem via verharde weg in hm
idem via semi-verharde weg in hm
idem over land in hm
idem over eigen grond in hm
idem via water in hm
idem totaal in hm
idem totaal voor de veldkavels in hm
gemiddelde schijnbare afstand van de grond totaal, in hm over de verharde weg
gemiddelde schijnbare afstand van de grond totaal voor de veldkavels in hm over de verharde weg
oppervlakte groenten en klein fruit in are (CBS)
oppervlakte pit- en steenvruchten in are (CBS)
oppervlakte bloem- en boomkwekerij in are (CBS)
oppervlakte bloembollen en -knollen in are (CBS)
oppervlakte tuinbouw onder glas in m2
SBE-totaal
SBE-totaal, grondgebonden
SBE-akkerbouw
SBE-rundveehouderij
SBE-extensieve tuinbouw
SBE-totaal, niet-grondgebonden

**SBE-intensieve tuinbouw**
**SBE-kalveren**
**SBE-gevogelte**
**hoofdberoep**
**aantal bedrijfskavels**
**aantal kavels**
**aantal kavels/percelen totaal**

**Attributes monitored on kavel/perceel level**
**dorpsbehoren van kavel of perceel**
**gemeentenummer van de gebruiker**
**gebruikernummer binnen de gemeente**
**nummer bedrijfskavel waarvan kavel/perceel deel uitmaakt**
**kavelnummer**
**(perceelnummer)**
**x-coordinaat van een centraal gelegen punt in kavel/perceel**
**y-coordinaat idem**
**oppervlakte van kavel/perceel in are**
**oppervlakte bouwland in are**
**oppervlakte grasland in are**
**oppervlakte erf in are**
**oppervlakte boomgaard en boomkwekerij in are**
**cultuurtoestand code**
**code bewerkelijkheid**
**aantal percelen per kavel**
**diepte van kavel op perceel in dam**
**afstand, in dam, bij huiskavel van centrum van bedrijfsgebouwen tot verst verwijderde punt van de grens**
**afstand van de grond tot het centrum van de bedrijfsgebouwen via verharde weg in hm**
**idem via semi-verharde weg in hm**
**idem via onverharde weg in hm**
**idem over land in hm**
**idem over water in hm**
**route-kenmerk**
**ontsluitingsafstand via semi-verharde weg in hm**
**idem via onverharde weg in hm**
**idem over land in hm**
**idem over water in hm**
**bodemtype en Gt**
**belemmeringen**
**ligging in gebied met bijzondere bestemming**
**vaknummer voor toedeling**
**toedelingscode**
**nummer van file met coordinaten van grenzen van kavels/percelen**
**recordnummer v/h centrale punt van kavel/perceel**
**aantal punten van de grens van kavel/perceel**

Within INTRANET use is made of a distinction between nodes as related to being the end-type node, significant node or intermediate node.
See figure A-2.1.

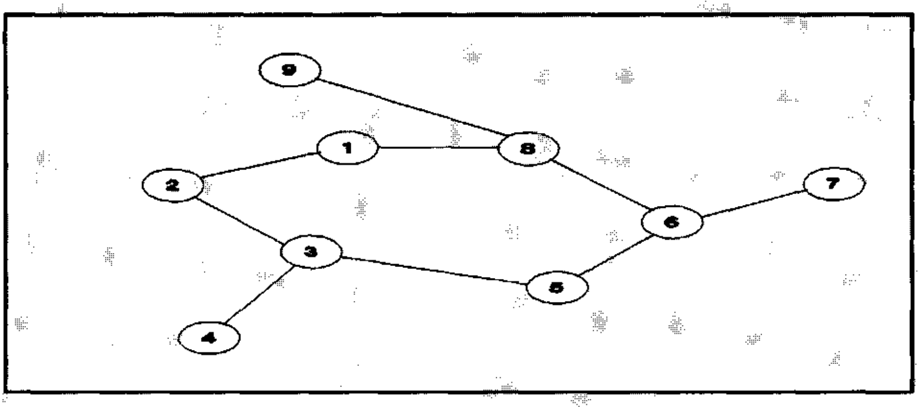



Figure A-2.1 An example of a network.

Nodes are called significant is they stand in direct connection with more than 2 other nodes of the network.
Nodes are called intermediate when they have direct connections with 2 other nodes only.
Nodes of end-type are those that have only one connection. Nodes 3,6,8 are significant.
In figure A-2.1 nodes 4,7,9 are of the end-type, while nodes 1,2,5 are of the intermediate type.

Within INTRANET a "straightforward" link-file (containing the links of the network as output of a digitizing program) is re-organized (into another file), such that can be easily read what node is in connection to what other node. To it is added the nearest significant node(s). A maximum of 6 connections per node has been set as system-parameterbound.

From figure A-2.1 the connectivity-matrix T-2.2 can be deducted, whereby for each node in known the node-number to which there is a link.
See Table T-2.2.

With INTRANET, the number of links per node is counted and thus can be decided whether a node is of intermediate, end or significant type.
For quick reference a 'separate' register is kept, showing the nearest significant node(s). See the 'addition' to matrix T-2.2.
Similar to the registration of links, a register with distances involved is made.

Table T-2.2. Connectivity-matrix belonging to figure A-2.1

| nodes | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| | 2 | 1 | 2 | 3 | 3 | 5 | 6 | 6 | 8 |
| | 8 | 3 | 5 | | 6 | 8 | | 1 | |
| | | | 4 | | | 7 | | 9 | |
| | 3 | 3 | | 3 | 3 | | 6 | | 8 |
| | 8 | 8 | | | 6 | | | | |

In a network the distance relationships between nodes can be represented by values in a matrix MAT, the entries of which, that is, its elements MAT(s,k), represent the distances d(s,k) between nodes s and nodes k.

Figure A-3 shows a network with 8 nodes. The links between nodes represent the direct connection between adjacent nodes. The figure also displays the length of the links.

The network can mathematically be represented by a matrix with distance values as shown in matrix-table T-3.1.

The matrix in Table T-3.1 shows values at the start of a shortest distance calculation.
The symbol * denotes: value yet unknown and is taken infinite large ∞.
Example:
The distance between node 1 and 2, i.e. d(1,2), has value 6.
This value can be found in row 1, column 2.

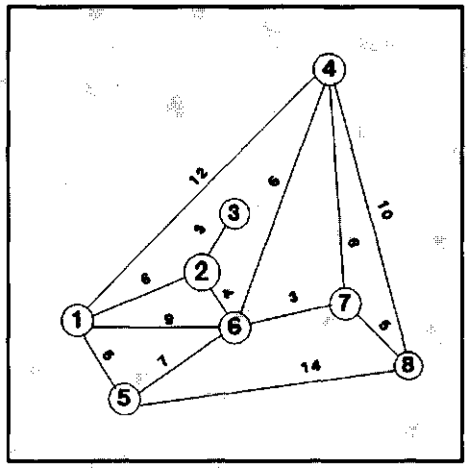


Figure A-3.1. A network with 8 nodes.

The positions (i,i) in matrix-table T-3.1 are zero, as these represent the distances of node i to itself.

Table T-3.1. Matrix-representation of figure A-3.1.

| row | column (and node) 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 6 | * | 12 | 5 | 9 | * | * |
| 2 | 6 | 0 | 3 | * | * | 4 | * | * |
| 3 | * | 3 | 0 | * | * | * | * | * |
| 4 | 12 | * | * | 0 | * | 6 | 6 | 10 |
| 5 | 5 | * | * | * | 0 | 7 | * | 14 |
| 6 | 9 | 4 | * | 6 | 7 | 0 | 3 | * |
| 7 | * | * | * | 6 | * | 3 | 0 | 5 |
| 8 | * | * | * | 10 | 14 | * | 5 | 0 |

*= value large/unknown

The basic procedure is the following:

step 0: select a node to start with, and call that node s;
step 1: let the known arc-distances between node s and all other nodes be the tentative shortest distances between node s and the other nodes;
step 2: find the minimum of all tentative shortest distances and label it the permanent shortest distance.
step 3: update all remaining tentative shortest distances d(s,k) by
    d(s,L) + d(L,k)
  if:
    d(s,L) + d(L,k) < d(s,k)
step 4: repeat step 2 and step 3 until all tentative shortest distances become permanent shortest distances.
step 5: repeat steps 1 - 4 with another node until all nodes have been processed.

The procedure applied to the network of Appendix 3, runs as follows:

step 0: start the procedure with node 1
step 1: take the known distances between node 1 and the others as start-values, (see Table T-3.1, Appendix 3) and label node 1;
----> result:

```
to node k : | 1 2 3 4 5 6 7 8
------------------------------------------
for s= 1 :  | 0 6 * 12 5 9 * *
```

now labeled : node 1
not yet labeled : 2,3,4,5,6,7,8

step 2: find the node with the shortest tentative distance and label that distance permanent shortest; label the k-node.
----> result: the shortest tentative distance within the series of unlabeled nodes is: d(1,5) = 5;
node 5 is to be labeled;
now labeled : 1,5
not yet labeled : 2,3,4,6,7,8

step 3: calculate all d(s,k) with s = 5 to all non-labeled nodes, i.e. to k = 2,3,4,6,7,8 and compare these values with the tentative known distances; update where a lower value is found;
----> result:

```
d(1,5)+d(5,2)=5+*   compare d(1,2)=6   -> d(1,2)=6
d(1,5)+d(5,3)=5+*   compare d(1,3)=*   -> d(1,3)=*
d(1,5)+d(5,4)=5+*   compare d(1,4)=*   -> d(1,4)=*
d(1,5)+d(5,6)=5+7   compare d(1,6)=9   -> d(1,6)=9
d(1,5)+d(5,7)=5+*   compare d(1,7)=*   -> d(1,7)=*
```

$d(1,5)+d(5,8)=5+14$ compare $d(1,8)=*$ -> $d(1,8)=19$

updating d(1,8) gives:

| to node k : | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| for s= 1 | 0 | 6 | * | 12 | 5 | 9 | * | 19 |

step 4: go to step 2; select the next shortest tentative distance;
---->result:
next shortest distance is d(1,2) with value 6;
now labeled : 1,2,5
not yet labeled : 3,4,6,7,8

step 3: calculate all d(s,k) with s=2 to all non-labeled nodes, i.e. k=3,4,6,7,8 and compare these with the tentative known distances;
---->result:
$d(1,2)+d(2,3)=6+3$ compare $d(1,3)=*$ -> $d(1,3)=9$
$d(1,2)+d(2,4)=6+*$ compare $d(1,4)=12$ -> $d(1,4)=12$
$d(1,2)+d(2,6)=6+4$ compare $d(1,6)=9$ -> $d(1,6)=9$
$d(1,2)+d(2,7)=6+*$ compare $d(1,7)=*$ -> $d(1,7)=*$
$d(1,2)+d(2,8)=6+*$ compare $d(1,8)=19$ -> $d(1,8)=19$

updating d(1,3) gives:

| to node k : | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| for s= 1 | 0 | 6 | 9 | 12 | 5 | 9 | * | 19 |

step 4: go to step 2; select the next shortest tentative distance, i.e. distance d(1,3) with value 9;
---->result:
now labeled : 1,2,3,5
not yet labeled : 4,6,7,8

step 3: calculate all d(s,k) with s=3 to all non-labeled nodes, i.e. to k=4,6,7,8 and compare these values with the tentative known distances;

no updating is necessary; the present result remains:

| to node k : | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| for s= 1 | 0 | 6 | 9 | 12 | 5 | 9 | * | 19 |

etc.;
the next node to be labeled is node 6 for d(1,6) with value 9
now labeled : 1,2,3,5,6

not yet labeled : 4,7,8

step 3: calculate all d(s,k) with s=6 to all non-labeled nodes, i.e. to k=4,7,8 and compare these values with the tentative known distances;
---->result:

| node k : | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| for s= 1 | 0 | 6 | 9 | 12 | 5 | 9 | 12 | 19 |

step 4: continuation of the procedure with node 4 labeled, gives:
now labeled : 1,2,3,4,5,6
not yet labeled : 7,8

step 3: calculate all d(s,k) with s=4 to all non-labeled nodes, i.e. to k=7,8 and compare these values with the tentative known distances;
----> result:

| to node k : | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| for s= 1 | 0 | 6 | 9 | 12 | 5 | 9 | 12 | 19 |

with node 7 labeled we have
now labeled : 1,2,3,4,5,6,7
still unlabeled : 8

step 3: calculate all d(s,k) with s=7 to all non-labeled nodes, i.e. to k=8 and compare this value with the tentative known distance;
---->result:

| to node k : | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| for s= 1 | 0 | 6 | 9 | 12 | 5 | 9 | 12 | 17 |

step 4: all nodes are labeled;
step 5: repeat the procedure for s=2, etc.

The application of the Dijkstra algorithm on the network, by application on all N rows, is the following:

| node: | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1: | 0 | 6 | 9 | 12 | 5 | 9 | 12 | 17 |
| 2: | 6 | 0 | 3 | 10 | 11 | 4 | 7 | 12 |
| 3: | 9 | 3 | 0 | 13 | 14 | 7 | 10 | 15 |
| 4: | 12 | 10 | 13 | 0 | 13 | 6 | 6 | 10 |
| 5: | 5 | 11 | 14 | 13 | 0 | 7 | 10 | 14 |
| 6: | 9 | 4 | 7 | 6 | 7 | 0 | 3 | 8 |
| 7: | 12 | 7 | 10 | 6 | 10 | 3 | 0 | 5 |
| 8: | 17 | 12 | 15 | 10 | 14 | 8 | 5 | 0 |

The application of the FLOYD1-procedure, used on the network presented with matrix T-3.1 in Appendix 3, runs as follows:
The basic idea of the shortest route and distance algorithm, as in the DIJKSTRA-procedure, is to compare tentatively known shortest distances MAT(s,k) with the sum of the values MAT(s,L) and MAT(L,k), L being any other node in the network.

step F1: start with node L=1, and let the arc-distances between node s=1 and all others be the tentative shortest distances between node s and the other nodes (k);
step F2: update all tentative shortest distances d(s,k) by substituting this value by d(s,L)+d(L,k) whenever smaller values can thus be obtained;
step F3: repeat step F2 for all nodes s, not yet processed;
step F4: repeat steps F1 through step F3 for all nodes L, not yet processed.

Intermediate results of this procedure on the network are:

steps F1-F3 taking L=1:

| to node k : | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| s= 1 L= 1 | 0 | 6 | * | 12 | 5 | 9 | * | * |
| s= 2 L= 1 | 6 | 0 | 3 | 18 | 11 | 4 | * | * |
| s= 3 L= 1 | * | 3 | 0 | * | * | * | * | * |
| s= 4 L= 1 | 12 | 18 | * | 0 | 17 | 6 | 6 | 10 |
| s= 5 L= 1 | 5 | 11 | * | 17 | 0 | 7 | * | 14 |
| s= 6 L= 1 | 9 | 4 | * | 6 | 7 | 0 | 3 | * |
| s= 7 L= 1 | * | * | * | 6 | * | 3 | 0 | 5 |
| s= 8 L= 1 | * | * | * | 10 | 14 | * | 5 | 0 |

example: for L=1, s=2, k=4 a replacement of d(2,4)=*
by d(2,1)+d(1,4)= 6+12 =18 has taken place.

step F4, take L=2; steps F1-F3 result in:

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| s= 1 L= 2 | 0 | 6 | 9 | 12 | 5 | 9 | * | * |
| s= 2 L= 2 | 6 | 0 | 3 | 18 | 11 | 4 | * | * |
| s= 3 L= 2 | 9 | 3 | 0 | 21 | 14 | 7 | * | * |
| s= 4 L= 2 | 12 | 18 | 21 | 0 | 17 | 6 | 6 | 10 |
| s= 5 L= 2 | 5 | 11 | 14 | 17 | 0 | 7 | * | 14 |
| s= 6 L= 2 | 9 | 4 | 7 | 6 | 7 | 0 | 3 | * |
| s= 7 L= 2 | * | * | * | 6 | * | 3 | 0 | 5 |
| s= 8 L= 2 | * | * | * | 10 | 14 | * | 5 | 0 |

step F4, take L=3; steps F1-F3 result in:

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| s= 1 L= 3 | 0 | 6 | 9 | 12 | 5 | 9 | * | * |
| s= 2 L= 3 | 6 | 0 | 3 | 18 | 11 | 4 | * | * |
| s= 3 L= 3 | 9 | 3 | 0 | 21 | 14 | 7 | * | * |
| s= 4 L= 3 | 12 | 18 | 21 | 0 | 17 | 6 | 6 | 10 |
| s= 5 L= 3 | 5 | 11 | 14 | 17 | 0 | 7 | * | 14 |
| s= 6 L= 3 | 9 | 4 | 7 | 6 | 7 | 0 | 3 | * |
| s= 7 L= 3 | * | * | * | 6 | * | 3 | 0 | 5 |
| s= 8 L= 3 | * | * | * | 10 | 14 | * | 5 | 0 |

step F4, take L= 4; steps F1-F3 result in:

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| s= 1 L= 4 | 0 | 6 | 9 | 12 | 5 | 9 | 18 | 22 |
| s= 2 L= 4 | 6 | 0 | 3 | 18 | 11 | 4 | 24 | 28 |
| s= 3 L= 4 | 9 | 3 | 0 | 21 | 14 | 7 | 27 | 31 |
| s= 4 L= 4 | 12 | 18 | 21 | 0 | 17 | 6 | 6 | 10 |
| s= 5 L= 4 | 5 | 11 | 14 | 17 | 0 | 7 | 23 | 14 |
| s= 6 L= 4 | 9 | 4 | 7 | 6 | 7 | 0 | 3 | 16 |
| s= 7 L= 4 | 18 | 24 | 27 | 6 | 23 | 3 | 0 | 5 |
| s= 8 L= 4 | 22 | 28 | 31 | 10 | 14 | 16 | 5 | 0 |

step F4, take L= 5; steps F1-F3 result in:

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| s= 1 L= 5 | 0 | 6 | 9 | 12 | 5 | 9 | 18 | 19 |
| s= 2 L= 5 | 6 | 0 | 3 | 18 | 11 | 4 | 24 | 25 |
| s= 3 L= 5 | 9 | 3 | 0 | 21 | 14 | 7 | 27 | 28 |
| s= 4 L= 5 | 12 | 18 | 21 | 0 | 17 | 6 | 6 | 10 |
| s= 5 L= 5 | 5 | 11 | 14 | 17 | 0 | 7 | 23 | 14 |
| s= 6 L= 5 | 9 | 4 | 7 | 6 | 7 | 0 | 3 | 16 |
| s= 7 L= 5 | 18 | 24 | 27 | 6 | 23 | 3 | 0 | 5 |
| s= 8 L= 5 | 19 | 25 | 28 | 10 | 14 | 16 | 5 | 0 |

step F4, take L= 6; steps F1-F3 result in:

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| s= 1 L= 6 | 0 | 6 | 9 | 12 | 5 | 9 | 12 | 19 |
| s= 2 L= 6 | 6 | 0 | 3 | 10 | 11 | 4 | 7 | 20 |
| s= 3 L= 6 | 9 | 3 | 0 | 13 | 14 | 7 | 10 | 23 |
| s= 4 L= 6 | 12 | 10 | 13 | 0 | 13 | 6 | 6 | 10 |
| s= 5 L= 6 | 5 | 11 | 14 | 13 | 0 | 7 | 10 | 14 |
| s= 6 L= 6 | 9 | 4 | 7 | 6 | 7 | 0 | 3 | 16 |
| s= 7 L= 6 | 12 | 7 | 10 | 6 | 10 | 3 | 0 | 5 |
| s= 8 L= 6 | 19 | 20 | 23 | 10 | 14 | 16 | 5 | 0 |

step F4, take L= 7; steps F1-F3 result in:

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| s= 1 L= 7 | 0 | 6 | 9 | 12 | 5 | 9 | 12 | 17 |
| s= 2 L= 7 | 6 | 0 | 3 | 10 | 11 | 4 | 7 | 12 |
| s= 3 L= 7 | 9 | 3 | 0 | 13 | 14 | 7 | 10 | 15 |
| s= 4 L= 7 | 12 | 10 | 13 | 0 | 13 | 6 | 6 | 10 |
| s= 5 L= 7 | 5 | 11 | 14 | 13 | 0 | 7 | 10 | 14 |
| s= 6 L= 7 | 9 | 4 | 7 | 6 | 7 | 0 | 3 | 8 |
| s= 7 L= 7 | 12 | 7 | 10 | 6 | 10 | 3 | 0 | 5 |
| s= 8 L= 7 | 17 | 12 | 15 | 10 | 14 | 8 | 5 | 0 |

step F4, next node L= 8; steps F1-F3 result in:

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| s= 1 L= 8 | 0 | 6 | 9 | 12 | 5 | 9 | 12 | 17 |
| s= 2 L= 8 | 6 | 0 | 3 | 10 | 11 | 4 | 7 | 12 |
| s= 3 L= 8 | 9 | 3 | 0 | 13 | 14 | 7 | 10 | 15 |
| s= 4 L= 8 | 12 | 10 | 13 | 0 | 13 | 6 | 6 | 10 |
| s= 5 L= 8 | 5 | 11 | 14 | 13 | 0 | 7 | 10 | 14 |
| s= 6 L= 8 | 9 | 4 | 7 | 6 | 7 | 0 | 3 | 8 |
| s= 7 L= 8 | 12 | 7 | 10 | 6 | 10 | 3 | 0 | 5 |
| s= 8 L= 8 | 17 | 12 | 15 | 10 | 14 | 8 | 5 | 0 |

The final solution is identical to the one found by an application of the Dijkstra algorithm, see Appendix 4.

Shortest distance calculations for networks with a multitude of nodes require substantial storage allocation besides considerable CPU-time. The more nodes involved, the larger the CPU-time and storage capacity needed.
The use of one-dimensional arrays (i.e. vectors) in combination with procedures sieving, shading and looping, proves worthwhile for reducing these needs.

**Sieving.**
The basic idea of the shortest route and distance algorithms is to compare tentatively known shortest distances MAT(s,k) with the sum of the values MAT(s,L) and MAT(L,k), L being any other node in the network.
Whenever a distance via the chosen intermediate node L becomes shorter than the tentatively known distance (TKD), the TKD gets upgraded and takes the lower value.

It can easily be understood that the above mentioned calculation:

$$MAT(s,k) = MAT(s,L) + MAT(L,k)$$

can be skipped in such cases where :

| | |
|---|---|
| s=L | [ then MAT(s,s)=0 ] |
| L=k | [ then MAT(k,k)=0 ] |
| s=k | [ then MAT(k,k)=0 ] |
| MAT(s,L)=* | |
| MAT(L,k)=* | |
| with * = value infinite large | |

Where s=L the value MAT(s,L) equals zero and the calculation should be skipped. Similarly in cases with L=k and s=k.

**Symmetrical Shading**
In the Floyd-algorithm, as presented by Yen (1975) -- see listing FLOYD1 in Appendix 13 -- , three loops can be seen:

```
do L= 1,N
   do s= 1,N
      do k= 1,N

      end do
   end do
end do
```

with
s,L,k: row-number, row-number, column-number
N : total number of nodes

In networks where values MAT(s,k) equal values MAT(k,s), it is not necessary to do the inner-loop completely, i.e the one: do k= 1,N .
The calculation burden can be reduced to approximately half, by changing the inner-loop to: do k= (s+1),N .
This is to be done in cases:

MAT(L,s)= MAT(s,L) for all situations L<s, (E5)

Whenever a new shortest distance MAT(s,k) is found, the value in the symmetric position MAT(k,s) of course is also found, the distances being equal. To be done therefore:

MAT(k,s)= MAT(s,k) for all new MAT(s,k) (E6)

Introducing such shading into the procedures, reduces the number of calculations to be done to approximately N.N.N/2, and is therefore very appropriate to use in cases with many nodes.

**Symmetrical Looping.**
A reduction in the number of calculations to be performed and thus in CPU-time required, also can be achieved by a technique Yen has called 'symmetrical looping'. This technique can be used for symmetric matrices/ networks as well as for asymmetric matrices. Yen uses, in addition to the technique of symmetrical shading, a calculation of MAT(s,k) within the cycle for MAT(k,s):

i.e. to MAT(s,k)= MAT(s,L) + MAT(L,k) (E7)

is added:

MAT(k,s)= MAT(k,L) + MAT(L,s) (E8)

In two-dimensional matrices subscripts s and k can be used to identify the position of the values of the distances between nodes s and k.

See Table T-3.1 in Appendix 3.
The first row contains the values for the distance of node 1 to itself and to all others; in the second row 2 those of node 2 to itself and to all others, etc.
Table T-7.1 shows the subscripts; the first subscript denotes the row-position of the element, the second subscript the column-position in the two-dimensional array. In position MAT(2,1) is therefore to be found the distance between node 2 and 1 of the network, equalling 6.

Table T-7.1. Subscripts.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1.1 | 1.2 | 1.3 | 1.4 | 1.5 | 1.6 | 1.7 | 1.8 |
| 2.1 | 2.2 | 2.3 | 2.4 | 2.5 | 2.6 | 2.7 | 2.8 |
| 3.1 | 3.2 | 3.3 | 3.4 | 3.5 | 3.6 | 3.7 | 3.8 |
| 4.1 | 4.2 | 4.3 | 4.4 | 4.5 | 4.6 | 4.7 | 4.8 |
| 5.1 | 5.2 | 5.3 | 5.4 | 5.5 | 5.6 | 5.7 | 5.8 |
| 6.1 | 6.2 | 6.3 | 6.4 | 6.5 | 6.6 | 6.7 | 6.8 |
| 7.1 | 7.2 | 7.3 | 7.4 | 7.5 | 7.6 | 7.7 | 7.8 |
| 8.1 | 8.2 | 8.3 | 8.4 | 8.5 | 8.6 | 8.7 | 8.8 |

From a mathematical point of view, it also must be noted that different notations can be used, for instance a one-dimensional array Y(i). In such arrays or vectors, Y(1) refers to the first element, Y(2) to the second, Y(3) to the third element, etc.

Taking values from a two-dimensional matrix and storing these into in such linear arrays might be done either column-wise or row-wise.
With a column-wise organization one gets:
Y(1) = MAT(1,1)
Y(2) = MAT(2,1)
Y(3) = MAT(3,1)
...... .........
With an organization along the rows this would lead to:
Y(1) = MAT(1,1)
Y(2) = MAT(1,2)
Y(3) = MAT(1,3)
...... .........

The two Vector Storage Modes are basically equal in value.
For a further explanation of the concept of storing the values of MAT(s,k) into a vector Y(i), the column-wise vector storage mode will be used.

Table T-7.2 shows how Y(i) can be fitted within MAT(s,k), the matrix showing

the index-values i in positions (s,k).
In the first 'column' the first eight index-values of entries Y(i) are positioned. They represent the positions of the values of entries MAT(s,1) with s=1,8.
In the second 'column' the next eight index-values, i.e. 9-16, are stored, indicating the positions of the values of entries Y(i) with i=9,16, corresponding with entries MAT(s,2) with s=1,8; etc.

Table T-7.2. Index-numbers of Y(i) within MAT(s,k) of the example network.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 9 | 17 | 25 | 33 | 41 | 49 | 57 |
| 2 | 10 | 18 | 26 | 34 | 42 | 50 | 58 |
| 3 | 11 | 19 | 27 | 35 | 43 | 51 | 59 |
| 4 | 12 | 20 | 28 | 36 | 44 | 52 | 60 |
| 5 | 13 | 21 | 29 | 37 | 45 | 53 | 61 |
| 6 | 14 | 22 | 30 | 38 | 46 | 54 | 62 |
| 7 | 15 | 23 | 31 | 39 | 47 | 55 | 63 |
| 8 | 16 | 24 | 32 | 40 | 48 | 56 | 64 |

Matrices T-7.1 and T-7.2 show the relationship between MAT(s,k) and Y(i).

Appendix 8 goes into storing of data of asymmetric networks; Appendix 9 does that for symmetric networks.

## VECTOR DATA STORAGE ASY FOR ASYMMETRIC NETWORKS

Asymmetric networks are networks where entries MAT(s,k) do not equal entries MAT(k,s). In that case, the network is called directed and represents occurring one-way flow.

Table T-8.1 shows the general relationship between (s,k) and (i), i.e. the relationship between matrix-values stored in position (s,k) of MAT(s,k)-matrices to those in position (i) of Y(i)-vectors, with MAT(s,k)-values taken column-wise (see Appendix 7).

Example: entry MAT(2,3) is to be found in Y((3-1).N+2), with N the number of nodes in the network.
For the N=8 matrix of Appendix 3, the MAT(2,3) value relates therefore to the entry Y((3-1).8+2)=Y(18). See also matrix-table T-7.2.

Therefore, using a notation Y(indexsk) rather than Y(i), the relationship between (s,k) and indexsk in a N-node matrix, can be written as:

indexsk= (k-1).N + s (E4)

Table T-8.1. Index-numbers (i) of a linear array Y(i) related to positions (s,k) of a matrix MAT(s,k) using all matrix positions.

| row number | column number 1 | 2 | 3 | .. | .. | k | .. | N |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | N+1 | 2N+1 | | .... | (k-1).N+1 | | |
| 2 | 2 | N+2 | 2N+2 | | .... | (k-1).N+2 | | |
| 3 | 3 | N+3 | 2N+3 | | .... | (k-1).N+3 | | |
| 4 | 4 | N+4 | .... | | .... | ......... | | |
| 5 | 5 | ... | .... | | .... | ......... | | |
| .. | .. | ... | .... | | .... | ......... | | |
| .. | .. | ... | .... | | .... | ......... | | |
| s | .. | ... | .... | | .... | ......... | | |
| .. | | | | | | | | |
| N | N | 2N | 3N | | .... | (k-1).N+N | | |

with N= total number of network nodes
s= row number
k= column number

The data storage procedure using a linear array in which are stored all data of a two-dimensional matrix, is referred to as having the asymmetric data in 'asymmetric storage mode' ASY.

## VECTOR STORAGE MODE SSM FOR SYMMETRIC NETWORKS

A symmetric networks is called undirected and represents two-way flow possibility. They can be represented by matrixes in which entries MAT(s,k) equal MAT(k,s) for all k and s.

Table T-9.1 shows the MAT(s,k) indexes of the lower half of MAT(s,k) including those in diagonal position.

Table T-9.1 Indexes of the lower-half of MAT(s,k).

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| 1.1 | . | . | . | . | . | . | . |
| 2.1 | 2.2 | . | . | . | . | . | . |
| 3.1 | 3.2 | 3.3 | . | . | . | . | . |
| 4.1 | 4.2 | 4.3 | 4.4 | . | . | . | . |
| 5.1 | 5.2 | 5.3 | 5.4 | 5.5 | . | . | . |
| 6.1 | 6.2 | 6.3 | 6.4 | 6.5 | 6.6 | . | . |
| 7.1 | 7.2 | 7.3 | 7.4 | 7.5 | 7.6 | 7.7 | . |
| 8.1 | 8.2 | 8.3 | 8.4 | 8.5 | 8.6 | 8.7 | 8.8 |

Using the vector storage mode, matrix-table T-9.2 shows how MAT(s,k) can be filled with Y(i), using the lower half of MAT(s,k) including the diagonal positions of MAT(s,k) only.

Table T-9.2. Index numbers (i) of a linear array Y(i) within the lower half of the matrix MAT(s,k).

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | - | - | - | - | - | - | - |
| 2 | 9 | - | - | - | - | - | - |
| 3 | 10 | 16 | - | - | - | - | - |
| 4 | 11 | 17 | 22 | - | - | - | - |
| 5 | 12 | 18 | 23 | 27 | - | - | - |
| 6 | 13 | 19 | 24 | 28 | 31 | - | - |
| 7 | 14 | 20 | 25 | 29 | 32 | 34 | - |
| 8 | 15 | 21 | 26 | 30 | 33 | 35 | 36 |

It can be seen that in the first 'column' there are N-elements; in the second 'column' one less: (N-1). In the third column only (N-2) elements are found, in the fourth only (N-3) , etc.

Table T-9.3 shows the index-numbers (i) of entries Y(i) in relation to the subscripts (s,k) of entries MAT(s,k), using only half the matrix MAT(s,k)

positions, including those on the diagonal.
This data storage procedure described above, with data stored in a linear array, using only 'half' of the two-dimensional matrix, is called bringing the data in 'single storage mode' SSM.

Table T-9.3. Index numbers for symmetric matrices in so-called 'single storage mode'.

| row number | column number 1 | 2 | 3 | .. | .. | k | | .. | N |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | - | - | - | - | - | - | - | |
| 2 | 2 | N+1 | - | - | - | - | - | - | |
| 3 | 3 | N+2 | 2N | - | - | - | - | - | |
| 4 | 4 | N+3 | 2N+1 | 3N-2 | - - | - | - | | |
| 5 | 5 | N+4 | 2N+2 | 3N-1 | 4N-5 | - | - | | |
| .. | .. | ... | ... | ... | ... | ... | ... | .. | |
| s | s | (N+1)+(s-k) | | ... | ... | ... | .. | | |
| .. | .. | ... | ... | ... | ... | ... | ... | .. | |
| N | N | 2N-1 | 3N-3 | 4N-6 | 5N-10 | ... | ... | .. | |

Proof of equations E1a, E2 and E3 for the transition of indexes of MAT(s,k) to those of Y(i) using the single storage mode SSM (see Appendix 9).
Looking at the index-values on the diagonal position of MAT(s,k) in matrix-table T-9.3 it can be seen that:

| | | |
|---|---|---|
| in row 1 : index11 = 1 | in general | : 1 |
| in row 2 : index22 = 9 | | : 1+(N) |
| in row 3 : index33 = 16 | | : 1+(N)+(N-1) |
| in row 4 : index44 = 22 | | : 1+(N)+(N-1)+(N-2) |
| in row 5 : index55 = 27 | | : 1+(N)+(N-1)+(N-2)+(N-3) |

with N = number of nodes in the case.

In it can be seen the regularity of a progression in which the value to be calculated, i.e. the index of the diagonal on position (s,s) of MAT(s,k) can be easily derived:

in row 2 the index22-value is: 1 + (N)
in row 3 the index33-value is: 1 + (N) + (N-1)
in row 4 the index44 value is: 1 + (N) + (N-1) + (N-2)
etc.

Leaving out the first value, i.e. 1, there is the progression:
... (a) + (a+v) + (a+2v) + ... + ...

of which is known :

\+ the j-th term $t_j$ in the progression has the value:

$$t_j = a+(j-1).v \tag{E9}$$

\+ the summation of the progression has the value:

$$\sum_{j=1}^{j=N} t_j = (a + t_j).j/2 \tag{E10}$$

in the example a = N and v = -1, thus:

$$t_j = N+(j-1).(-1) = N-j+1 \tag{E11}$$

$$\sum_{j=1}^{j=N} t_j = (N+N-j+1).j/2 = (2N-j+1).j/2 \tag{E12}$$

As the progression started out with the second row of Mat(s,k), the j in the progression has to be interpreted as being (s-1).
Also the value 1, which was left out, has to be added again.

It then follows that:

$$
\begin{aligned}
\text{indexss} &= 1+(2N-(s-1)+1).(s-1)/2 \\
&= 1+(2N-s+2).(s-1)/2 \\
&= (s-1).(N-s/2)+s
\end{aligned} \tag{E1b}
$$

Application of this rule the network of Appendix 3, gives:

row 1: index11 = (1-1).(8-1/2) + 1 = 1
row 2: index22 = (2-1).(8-2/2) + 2 = 9
row 3: index33 = (3-1).(8-3/2) + 3 = 16
row 4: index44 = (4-1).(8-4/2) + 4 = 22

As can easily be seen, each following index-number in each column has the index-number of the diagonal in that column, indexkk, upgraded by the value (s-k). This is true in those cases where $s>k$, thus:

$$\text{indexsk} = \text{indexkk} + (s-k) \quad \text{for all cases } s>k \tag{E2}$$

In cases where $s<k$, the value MAT(s,k) equals the value MAT(k,s) which index can be found according to the equation given above, substituting k for s and visa versa.
This therefore leads to:

$$\text{indexsk} = \text{indexss} + (k-s) \quad \text{for all cases } s<k \tag{E3}$$

Similarly to eqn. E1b it follows that:

$$\text{indexkk} = (k-1).(N-k/2)+k \tag{E1a}$$

ALG332 of Yen (see Appendix 16) has lead to the writing of ALGSSM1, using vector storage mode (VSM) rather than matrix storage mode (MSM).
Use is made of the vector Y(i), in which 'half' of the data of MAT(s,k) has been stored. See also Appendix 9.

ALGSSM2 (see Appendix 22) was derived at replacing multiplications within ALGSSM1 by summations and using variables called minorLL, minorss and minorkk.

Notice that within the algorithm three loops occur:

- do L=1,N
- do s=1,N
- do k=s+1,N

At the beginning, the procedure starts off with L=1, s=1 and k=2.
In stead of using MAT(s,L), Y(indexsL) is used; Y(indexLk) in stead of MAT(L,k), etc.:

MAT(v,w) <---> Y(indexvw) for v=L,s,k
and w=L,s,k

The index-values to be used, can be determined with eqn. E1a, E2 and E3 (see also Appendix 10):

| | | | |
|---|---|---|---|
| indexsk | = indexss + (k-s) | ( s<k ) | (E3) |
| indexkk | = (k-1).(N-k/2)+k | | (E1a) |
| indexss | = (s-1).(N-s/2)+s | | (E1b) |

Example:
with 8 nodes (i.e. with N=8, see also tables A-9.1 and A-9.2 in Appendix 9), remembering L=1, s=1 and k=2:

indexsk = 2
indexkk = 9
indexss = 1

At the start, indexkk takes the value (N+1).
Therefore, in general (see also Appendix 22):

indexsk = 2
indexkk = N+1
indexss = 1

Within ALGSSM2, use is made of variables minorLL, minorss and minorkk, which values have been defined as follows:

$$\text{minortt} = \text{indextt-t} \qquad \text{for } t=L,s,k \tag{E13}$$

For notation purposes within this appendix, a distinction is made between the values of minorLL with L=2 versus the value when L=1.
The new minorLL value will be addressed to with *minorLL;* the present value will be addressed to with: minorLL.
Similarly we will use *minorss* with s upgraded versus minorss, *minorkk* versus minorkk with k upgraded to *k* from k. To indicate changes in s, use will be made of variables s and *s*.
*Indexkk* will refer to a new indexkk with k upgraded, etc.

*derivation of index-values for minor-variables within the k-loop:*

For the first round, with L=1, s=1, k=2, the following is true:
(See also Appendix 22)

$$\begin{aligned} \text{minorLL} &= 0 \\ \text{minorss} &= 0 \\ \text{minorkk} &= N-1 \end{aligned}$$

The minor-values to be used in the k=3 iteration, can be derived from the values in the k=2 iteration.
In general: the values in a new k iteration can be derived from those in the former iteration.

Eqn. 1a reads:

$$\text{indexkk} = (k-1).(N-k/2)+k \tag{E1a}$$

Using the temporarily notation, this can be read as:

$$\textit{indexkk} = (\textit{k} -1).(N-\textit{k}/2) + \textit{k} \tag{E1a1}$$
$$\text{indexkk} = (k-1).(N-k/2) + k \tag{E1a2}$$

With

$$\textit{k} = k+1 \tag{E14}$$

it follows that:

$$\begin{aligned} \textit{indexkk} &= (k+1-1).(N-(k+1)/2))+ k+1 \\ &= k.(N-k/2) - k/2 + k+1 \end{aligned} \tag{E15}$$

leading to:

$$\begin{aligned} \textit{indexkk} - \text{indexkk} &= 1.(N-k/2) - k/2 + 1 \\ &= N-k+1 \end{aligned} \tag{E16}$$

or

$$\mathit{indexkk} = \text{indexkk} + (\text{N-k/2}) - \text{k/2} + 1$$
$$= \text{indexkk} + \text{N-k+1} \qquad \textbf{(E17)}$$

With eqn. E13, it then also follows that:

$$\mathit{minorkk} = \text{indexkk} + \text{N-k+1} - \mathit{k}$$
$$= \text{minorkk} + \text{k} + \text{N-k+1} - (\text{k}+1)$$
$$= \text{minorkk} + \text{N} - \text{k} \qquad \textbf{(E18)}$$

In Fortran-code (see Appendix 22):

```
minorkk      = minorkk + N - k
```

*derivation of index-values for indexsk within the k-loop:*

Within the inner-loop, use is also made of indexsk. With a new k-value (*k*), the value of the new indexsk (*indexsk*) can easily be derived from the former indexsk-value.
Substituting eqn. E1b in eqn. E3, it follows f.i. that:

$$\mathit{indexsk} = (\text{s-1}).(\text{N-s/2}) + \text{s} + \mathit{k} - \text{s}$$
$$= (\text{s-1}).(\text{N-s/2}) + \mathit{k} \qquad \textbf{(E19)}$$

with a substitution of eqn. E14, eqn. E19 reads:

$$\mathit{indexsk} = (\text{s-1}).(\text{N-s/2}) + \text{k} + 1$$
$$= \text{indexsk} + 1 \qquad \textbf{(E20)}$$

In Fortran-code, in general therefore:

```
indexsk      = indexsk + 1
```

The indexsk can thus be upgraded with the value 1 to find the indexsk-value for the next iteration within the k do-loop.

*derivation of index-values within the s-loop:*

Starting a new iteration in the s do-loop, L=1, s=2 and k=3.
A new indexsk-value (*indexsk*) is to be used. This can be found by upgrading the value used last (indexsk), by 1, according to eqn. E20.

Similar to the deduction of eqn. E17 and E18 it can be deducted that:

$$indexss = indexss + N\text{-}s+1 \tag{E21}$$
$$minorss = minorss + N\text{-}s \tag{E22}$$

Within the new s-round, at the start of the new k-do-loop, again a new starting value for minorkk (*minorkk*) has to be determined.

Knowing:

$$k = s+1 \tag{E23}$$

it can be derived from eqn. E21 that:

$$indexkk = indexss + N\text{-}s+1 \tag{E24}$$

and with eqn. E14 it then follows that:

$$\begin{aligned} minorkk &= indexkk - k \\ &= indexss + N\text{-}s+1 - k \\ &= indexss + N\text{-}s+1 - s - 1 \\ &= minorss + N\text{-}s \end{aligned} \tag{E25}$$

A new value of minorkk has to be determined and assigned in the previous s-loop; in Fortran-code eqn. E25 therefore has to be written as:

$$\text{minorkk} = \text{minorss} + N - s - 1 \tag{E26}$$

*derivation of index-values for minorLL within the L-loop:*

Starting a new L-do-loop, eqn. E18 can be used to derive the new minorLL-value (*minorLL*), within the former L-iteration:

$$minorLL = minorLL + N - L \tag{E27}$$

ALGASY1 (see the listing in Appendix 24) is similar to ALG332 (see the listing in Appendix 16), but uses asymmetric vector-storage-mode in stead of the usual matrix storage mode.
In ALGASY1 all entries MAT(s,k) are stored into a vector Y(indexsk). See Appendix 8 for details.
Likewise the creation of ALGSSM2 (see Appendix 11 and 22), a number of calculations to be performed, has been taken into the outer-loopings of the procedure. Due to the use of the ASY-mode in stead of the SSM-mode, the indexsk-formulas differ from those used in ALGSSM2.
See Appendix 25 for the listing of ALGASY2.

*derivation of index-values within the k-loop:*

Within the k-do-loop of asymmetric networks the index-values indexsk, indexks, indexLk and indexkL have to be determined. Let the new index-values be *indexsk, indexks, indexLk* and *indexkL.*

Equation E4, chapter 4, reads:

$$\text{indexsk} = (k-1).N+s \qquad \text{(E4)}$$

It then follows that:

$$\textit{indexsk} = (\textit{k} -1).N+s \qquad \text{(E4a)}$$

With:

$$\textit{k} = k+1 \qquad \text{(E28)}$$

it then also follows that:

$$\begin{aligned} \textit{indexsk} &= k.N+s \\ &= \text{indexsk}+ N \qquad \text{(E29)} \end{aligned}$$

Eqn. E4 can be also be read as:

$$\text{indexks} = (s-1).N+k \qquad \text{(E4b)}$$

leading to:

$$\textit{indexks} = (s-1).N+ \textit{k} \qquad \text{(E30)}$$

Substituting eqn. E28, eqn. E30 can be rewritten, leading to:

$$\begin{aligned} \textit{indexks} &= (s-1).N + k + 1 \\ &= \text{indexks} + 1 \qquad \text{(E31)} \end{aligned}$$

Similarly, for the determination of the subsequent indexLk- and inkexkL-values within the k-do-loop:

$$\textit{indexLk} = \text{indexLk} + N \tag{E32}$$

and

$$\textit{indexkL} = \text{indexkL} + 1 \tag{E33}$$

*derivation of index-values within the s-loop:*

With a new s-value, the inner loop (i.e. the k-loop), starts off with a new k-value ($k$). The new indexsk-value (*indexsk*) can be determined by adding the value 1 to the last one used (i.e. indexsk) in the former k-loop, according to eqn. E31:

$$\textit{indexsk} = \text{indexsk} + 1$$

The new indexsk-value can also be determined by using the init-indexsk value (irsk) of the former s-loop and can be written as (see Appendix 25):

$$\textit{indexsk} = \text{irsk} + N + 1 \tag{E34}$$

By similar reasoning, for a new s-iteration, it follows that:

$$\textit{indexsL} = \text{indexsL} + 1 \tag{E35}$$
$$\textit{indexLs} = \text{indexLs} + N \tag{E36}$$
$$\textit{indexks} = \text{indexks} + N + 1 \tag{E37}$$

and

$$\textit{indexLk} = \textit{indexLs} + N \tag{E38}$$
$$\textit{indexkL} = \textit{indexsL} + 1 \tag{E39}$$

*derivation of index-values within the L-loop:*

With a new L-value in the L-do-loop, new index-values have to be used for indexsL, indexkL, indexLs and indexLk. Again the s-value starts off with $s=1$. The other index-values are derived in the same manner as above, leading to:

$$\textit{indexsL} = \text{indexsL} + N \tag{E40}$$
$$\textit{indexkL} = \text{indexsL} + 1 \tag{E41}$$
$$\textit{indexLs} = \text{indexLs} + 1 \tag{E42}$$
$$= L+1 \tag{E43}$$
$$\textit{indexLk} = \textit{indexLs} + N \tag{E44}$$

```
!------------------------------------------------------------------------
! This subroutine contains the algorithm of Floyd for asymmetric matrices in its
! most bare form.
!------------------------------------------------------------------------
! MAT(s,k)  : matrix filled with values for distance d(s,k)
! z         : MAT(s,L)+MAT(L,k)
! N         : number of nodes
! inf       : value for infinite distance
! s, L, k   : nodes of the matrix
!------------------------------------------------------------------------
      integer          MAT(20,20)          ! N,N
      integer          INF, z, s, L, k
      integer          N

      do L=1,N
         do s=1,N
            do k=1,N

                z = MAT(s,L)+MAT(L,k)

                if (z.lt.MAT(s,k)) then
                      MAT(s,k)=z
                end if

            end do                         ! end do k
         end do                            ! end do s
      end do                               ! end do L
      RETURN
      END ! SUBROUTINE FLOYD1
```

SUBROUTINE DIJKDREV (MAT,N,INF) **APPENDIX 14**

```
!-----------------------------------------------------------------------
! this subroutine contains the algorithm of Dijkstra with the so-called adaption
! of Dreyfus with the use of a row vector F
!-----------------------------------------------------------------------

      integer        MAT(20,20) ,F(20),R,Z,REF,INF       ! N,N
      integer        H(20),KK,L,S,I,J,K,N                ! N

      DO s=1,N                                  ! S= starting point
        KK=0                                    ! initialize node
        L=s                                     ! address first label
        do i=1,N                                ! all labels temporarily zero
          H(i)=0
          F(i)=MAT(L,i)                         ! put row into vector
        end do
        H(s)=1                                  ! assign first fixed label
        DO j=2,N
          R=INF                                 ! give value for infinite
          DO k=1,N
            if (k.ne.s) then
                REF=MAT(s,k)                    ! latest known distance
            end if
            if ((k.ne.s).and.(H(k).lt.1)) then
                Z=F(L) + MAT(L,k)
            end if
            if ((k.ne.s).and.(H(k).lt.1).and.
     1          (Z.lt.REF)) then                ! a shorter route found
                F(k)    = Z
                MAT(s,k)= F(k)
                REF     = Z
            end if
            if ((k.ne.s).and.(H(k).lt.1).and.
     1          (z.ge.REF).and.(REF.lt.R)) then
                R = REF                         ! no short route found
                KK= k
            end if
          END DO                                ! end do k
          IF (KK.ne.0) THEN
            L=KK                                ! new node for L
            H(L)=1                              ! permanent label for L
          END IF
        END DO                                  ! end do j
      END DO                                    ! end do s
      RETURN
      END !* SUBROUTINE DIJKDREV
```

```
!----------------------------------------------------------------------
! this subroutines contains the algorithm of Dijkstra with an adaption of Yen;
! a row-vector FS is used
!----------------------------------------------------------------------

integer         MAT(20,20),INF,X,Z                    ! N,N
integer         S,I,J,K,L,KX,KH,H(20),FS(20)          ! N
integer         G,N,t

      DO S=1,N
        L=S
        G=N
        DO t=1,N
            H(t)=t
            FS(t)=MAT(L,t)                          ! put row s in vector
        END DO
        H(1)=S
        H(S)=1
        DO I=2,N
            X=INF
            DO J=2,G
                  K= H(J)
                  Z= FS(L)+MAT(L,K)
                  IF (Z.LT.FS(K)) THEN
                     FS(K)=Z
                  END IF
                  IF (X.GT.FS(K)) THEN
                        X = FS(K)
                        KX= K
                        KH= J
                  END IF
            END DO

            L    = KX
            H(KH)= H(G)
            G    = G-1
            DO t=1,N                                ! put vector back
                  MAT(s,t)=FS(t)                    ! into matrix
            END DO
         END DO
      END DO
      RETURN
      END !* SUBROUTINE ALG023
```

```
!-----------------------------------------------------------------------------
! This subroutines contains the algorithm for matrices according to procedures
! of Yen
!-----------------------------------------------------------------------------

      integer        MAT(20,20)                         ! N,N
      integer        X,Z,Y
      integer        s,L,k
      integer        N, tel3, INF

      INF2=2*INF
      DO L=1,N
        DO s=1,N
           Z=MAT(L,s)+MAT(s,L)
           IF (Z.LT.INF2) THEN
             IF (Z.LT.MAT(s,s)) MAT(s,s)=Z
             tel3=s+1
             DO k=TEL3,N
                X=MAT(s,L)+MAT(L,k)                     ! s->L->k
                IF (X.LT.MAT(s,k)) MAT(s,k)= X
                Y=MAT(k,L)+MAT(L,s)                     ! k->L->s
                IF (Y.LT.MAT(k,s)) MAT(k,s)= Y
             END DO                                     ! end k
           END IF                                       ! end <
        END DO                                          ! end s
      END DO                                            ! end L
      RETURN
      END !* SUBROUTINE ALG332
```

```
!------------------------------------------------------------------------
! This subroutine contains the algorithm of Floyd for asymmetric matrices,
! making use of if-statements for sieving and skipping singular cases where no
! calculations have to be done.
! Use FLOYDs for symmetric matrices; that goes faster than this one which
! can process symmetric matrices as well of course.
!------------------------------------------------------------------------
! MAT(s,k)        : matrix filled with values for distances d(s,k)
! z               : MAT(s,L)+MAT(L,k)
! N               : number of nodes
! inf             : value for infinite distance
! s, L, k         : nodes of the matrix
! case 1          : starting node is intermediate node
! case 2          : last node is intermediate node
! case 3          : starting node s is last node k
! case 4          : distance from node s to intermediate L is infinite
! case 5          : distance from intermediate L to last node is infinite
!------------------------------------------------------------------------

      integer        MAT(20,20)                    ! N,N
      integer        INF, z, s, L, k
      integer        N

      do L=1,N
        do s=1,N
           if (s.ne.L) then                        ! if not case1
             if (MAT(s,L).lt.INF) then             ! if not case4
                 do k=1,N
                     if (k.ne.L.or.k.ne.s) then    ! if not 2,3
                        if (MAT(L,k).lt.INF) then
                                                   ! if not case5
                          z=MAT(s,L)+MAT(L,k)

                          if (z.lt.MAT(s,k)) then
                            MAT(s,k)=z
                          end if
                        end if
                     end if
                 end do                            ! end do k
             end if
           end if
        end do                                     ! end do s
      end do                                       ! end do L
      RETURN
      END ! SUBROUTINE FLOYD2
```

```
!------------------------------------------------------------------------
! This subroutine contains the algorithm of FLOYD for symmetric matrices
!------------------------------------------------------------------------
! MAT(s,k)        : matrix filled with values for distance d(s,k)
! z               : MAT(s,l)+MAT(l,k)
! N               : number of nodes
! inf             : value for infinite distance
! s, l, k         : nodes of the matrix
! case 1          : starting node is intermediate node
! case 2          : last node is intermediate node
! case 3          : starting node s is last node k
! case 4          : distance from node s to intermediate l is infinite
! case 5          : distance from intermediate l to last node is infinite
!------------------------------------------------------------------------
      integer        MAT(20,20)                    ! N,N
      integer        INF, z, s, k
      integer        N, tel3

      do L=1,N
        do s=1,N
           if (s.ne.L) then                        ! if not case 1
             if (MAT(s,L).lt.INF) then             ! if not case 4
                tel3=s+1
                do k=tel3,N
                  if (k.ne.L) then                 ! if not case 2
                     if (MAT(L,k).lt.INF) then
                                                   ! if not case 5
                       if (L.lt.s) then            ! use sym.case
                          MAT(s,L)=MAT(L,s)
                       end if

                       z=MAT(s,L)+MAT(L,k)

                       if (z.lt.MAT(s,k)) then
                          MAT(s,k)=z
                          MAT(k,s)=MAT(s,k)        ! sym.situation
                       end if
                     end if
                  end if
                end do                             ! end do k
             end if
           end if
        end do                                     ! end do s
      end do                                       ! end do L
      RETURN
      END ! SUBROUTINE FLOYDs
```

```
!-----------------------------------------------------------------------
! this subroutine contains the algorithm of Dijkstra with the so-called adaption
! of Dreyfus;
! matrix-mode is used; the algorithm was derived from DIJKDREV,
! Appendix14.
!-----------------------------------------------------------------------

      integer          MAT(20,20)          ! N=20
      integer          R,Z,REF,INF
      integer          H(20),KK,L,S,I,J,K,N

      do s=1,N                             ! S= starting point
         KK=0                              ! initialize node
         L=s                               ! address first label
         do i=1,N                          ! all labels temp zero
            H(i)=0
         end do
         H(s)=1                            ! assign first fixed label
         do j=2,N
            R=INF                          ! give value for infinite
            do k=1,N
               if (k.ne.s) then
                  REF=MAT(s,k)             ! latest known distance
               end if
               if ((k.ne.s).and.(H(k).lt.1)) then
                  Z=MAT(s,L) + MAT(L,k)
               end if
            if ((k.ne.s).and.(H(k).lt.1).and.
     1            (Z.lt.REF)) then         ! shorter route found
                  MAT(s,k)=Z
                  REF=Z
               end if
               if ((k.ne.s).and.(H(k).lt.1).and.
     1            (z.ge.REF).and.(REF.lt.R)) then
                  R=REF                    ! no shorter route found
                  KK=k
               end if
            end do                         ! end k
            IF (KK.ne.0) THEN
               L=KK                        ! new node for L
               H(L)=1                      ! permanent label for L
            END IF
         end do
      end do
      RETURN
      END !* SUBROUTINE DIJKDREM
```

```
!-----------------------------------------------------------------------------
! this subroutines contains the algorithm of Dijkstra with an adaption of Yen;
! matrix-forms are used
!-----------------------------------------------------------------------------

      integer     MAT(20,20)                ! N,N
      integer     INF,X,Y
      integer     S,I,J,K,L,KX,KH,H(20)
      integer     G,N

      DO S=1,N
        L=S                                 ! start with S
        G=N
        DO I=1,N
            H(I)=I
        END DO
        H(1)=S
        H(S)=1
        DO I=2,N
           X=INF
           DO J=2,G
                K= H(J)
                Y= MAT(S,L)+MAT(L,K)
                IF (Y.LT.MAT(S,K)) THEN
                     MAT(S,K)=Y
                END IF
                IF (X.GT.MAT(S,K)) THEN
                     X = MAT(S,K)
                     KX= K
                     KH= J
                END IF
           END DO                           ! end do j

           L    = KX
           H(KH)= H(G)
           G    = G-1
        END DO                              ! end do i
      END DO                                ! end do s
      RETURN
      END !* SUBROUTINE ALG023m
```

```
!------------------------------------------------------------------------
! This subroutine contains an adapted ALG332-algorithm with use of vector
! mode and symmetric storage for faster access
!------------------------------------------------------------------------

      integer        N, L, s, k, z, X
      integer        Y(400)                              ! N*N
      integer        indexsl, indexlk, indexss
      integer        indexsk, indexkk, indexll
      integer        INF, tel3

      INF2= 2*INF
      do L=1,N
        indexll= (L-1)*(N-(1.0*L/2))+L
        do s=1,N
           indexss= (s-1)*(N-(1.0*s/2))+s
           IF (s.lt.L) THEN
                indexsl= indexss+(L-s)
           ELSE
                indexsl= indexll+(s-L)
           END IF

           Z= 2.0*Y(indexsl)
           IF (Z.LT.INF2) THEN
                tel3=s+1
                DO k=tel3,N
                     indexkk= (k-1)*(N-(1.0*k/2))+k
                     indexsk= indexss+(k-s)              ! k always> s
                     IF (L.lt.k) then
                       indexlk= indexll+(k-L)
                     ELSE
                       indexlk= indexkk+(L-k)
                     END IF

                     X= Y(indexsl)+Y(indexlk)

                     IF (X.LT.Y(indexsk)) then
                       Y(indexsk)= X
                     END IF
                END DO                                    ! end k
           END IF                                         ! end <
        end do                                            ! end s
      end do                                              ! end L
      RETURN
      END !* SUBROUTINE ALGSSM1
```

```
!-----------------------------------------------------------------------
! This routine contains an adapted ALGSSM1 algorithm with use of vector
! mode and symmetric storage for faster access
!-----------------------------------------------------------------------
      integer        N,s,L,k,z,X,Y(400)
      integer        indexsl, indexlk, indexsk, tel3, INF
      integer        minorll, minorss, minorkk

      minorll= 0                                    ! indexll-L
      do L=1,N
        indexsk= 2
        minorkk= N-1                                ! indexkk-k
        minorss= 0                                  ! indexss-s
        do s=1,N
           if (s.le.L) then
                indexsl= minorss+L
           else
                indexsl= minorll+s
           end if
           IF (Y(indexsl).lt.INF) then
                TEL3=s+1
                do k= tel3,N
                     if (L.le.k) then
                          indexlk= minorll+k
                     else
                          indexlk= minorkk+L
                     end if
                     X= Y(indexsl)+Y(indexlk)
                     if (X.LT.Y(indexsk)) then
                          Y(indexsk)= X
                     end if
                     indexsk= indexsk+1
                     minorkk= minorkk+N-k
                end do                              ! end do k
           ELSE
                indexsk= indexsk+N-s
           END IF
           indexsk= indexsk+1
           minorss= minorss+N-s
           minorkk= minorss+N-s-1
        end do                                      ! end do s
        minorll= minorll+N-L
      end do                                        ! end do L
      RETURN
      END !* SUBROUTINE ALGSSM2
```

**SUBROUTINE ALGSSM3 (Y,N,INF)** **APPENDIX 23**

```
!-----------------------------------------------------------------------
! This subroutine contains an algorithm with vector mode and symmetric
! storage for faster access;
! the main diagonal of MAT(i,i) is left out.
!-----------------------------------------------------------------------
      integer         N,s,L,k,z,X,Y(400)
      integer         indexsl, indexlk, indexsk, tel3, INF
      integer         majorll, majorss, majorkk

      majorll= 1                                        ! index(L+1,L)
      do L=1,N
        indexsk= 1
        majorkk= N                                      ! index(k+1,k)
        majorss= 1                                      ! index(s+1,s)
        do s=1,N
           if (s.lt.L) then
             indexsl= majorss-s-1+L
           else
             indexsl= majorll-L-1+s
           end if
           IF (Y(indexsl).lt.INF) then
             TEL3= s+1
             do k= tel3,N
                    if (L.lt.k) then
                          indexlk= majorll-L-1+k
                    else
                          indexlk= majorkk-k-1+L
                    end if
                    X= Y(indexsl)+Y(indexlk)
                    if (X.LT.Y(indexsk)) then
                          Y(indexsk)= X
                    end if
                    indexsk= indexsk+1
                    majorkk= majorkk+N-k
             end do                                     ! end do k
           ELSE
             indexsk= indexsk+N-s
           END IF
           majorss= majorss+N-s
           majorkk= majorss+N-s-1
        end do                                          ! end do s
        majorll= majorll+N-L
      end do                                            ! end do L
      RETURN
      END !* SUBROUTINE ALGSSM3
```

```
!------------------------------------------------------------------------
! This subroutine contains ALGSSM but adapted for processing non-symmetric
! matrices.
!------------------------------------------------------------------------
      integer          Z,X,W
      integer          tel3
      integer          indexsl, indexsk, indexlk
      integer          indexls, indexks, indexkl
      integer          INF, INF2
      integer          N, s, L
      integer          Y(400)                          ! N*N

      INF2  = 2*INF
      DO L=1,N
         DO s=1,N
            indexls=(s-1)*N+L                          ! get indexls
            indexsl=(l-1)*N+s                          ! get indexsl

            Z=Y(indexsl)+Y(indexls)

            IF (Z.LT.INF2) THEN
               TEL3=s+1
               DO k=TEL3,N
                  indexlk=(k-1)*N+L                    ! s-->L-->k
                  X=Y(indexsl)+Y(indexlk)
                  indexsk=(k-1)*N+s
                  IF (X.LT.Y(indexsk)) then
                     Y(indexsk)=X
                  END IF

                  indexks=(s-1)*N+k                    ! k-->L-->s
                  indexkl=(L-1)*N+k
                  W=Y(indexkl)+Y(indexls)
                  IF (W.LT.Y(indexks)) then
                     Y(indexks)=W
                  END IF
               END DO
            END IF
         END DO
      END DO

      RETURN
      END  !* SUBROUTINE ALGASY1
```

```
!-------------------------------------------------------------
! This subroutine contains ALGSSM2 but adapted for
! processing non-symmetric matrices.
!-------------------------------------------------------------
      integer       Z,X,W,INF,INF2, N,s,L, tel3 ,Y(400)    ! N*N
      integer       indexsl, indexsk, indexlk
      integer       indexls, indexks, indexkl

      INF2   = 2*INF
      indexsl= 1
      irsl   = 1
      indexls= 1
      indexkl= 2
      indexlk= N+1
      do L=1,N
        indexsk= N+1
        irsk   = indexsk
        indexks= 2
        irks   = indexks
        do s=1,N
          Z=Y(indexsl)+Y(indexls)
          IF (Z.lt.INF2) then
            TEL3= s+1
            do k= TEL3,N
                X= Y(indexsl)+Y(indexlk)
                if (X.LT.Y(indexsk)) then
                  Y(indexsk)= X
                end if
                W= Y(indexkl)+Y(indexls)
                if (W.LT.Y(indexks)) then
                  Y(indexks)= W
                end if
                indexsk= indexsk+N
                indexks= indexks+1
                indexlk= indexlk+N
                indexkl= indexkl+1
            end do                          ! end do k
          END IF
          indexsl= indexsl+1
          indexkl= indexsl+1
          indexls= indexls+N
          indexlk= indexls+N
          indexsk= irsk+N+1
          irsk   = indexsk
          indexks= irks+N+1
          irks   = indexks
        end do                              ! end do s
```

```
  indexsl= irsl+N
  irsl   = indexsl
  indexkl= indexsl+1
  indexls= L+1
  indexlk= indexls+N
end do                                  ! end do L
RETURN
END  !* SUBROUTINE ALGASY2
```

Because of the need to interpret ecological infrastructure networks within the framework of landuse planning, it is necessary to:

a) draw the 'minimum' spanning tree;
b) pinpoint the most vulnerable link, i.e. the one with maximum length, its subsequent, the following, etc.;
c) draw the route through the ecological network from node to node, i.e. on the basis of exercising a least-effort leap for each node-to-node connection;
d) draw the nodes within a certain reach of any particular node, making use of the ecological network, rather than by shortest direct route.

The request b) involves finding the largest distance stored in the network-matrix NETMAT, the largest but one, etc.
The request c) can be solved by storing relationships between the nodes of the network.
Within the ECONET-procedures use is made of storage-matrixes SM1 and SM2, into which individual and collective spatial relations are stored. These relate to dendrogram-relations.
An example is given with a set of 32 nodes spatially ordered as in figure A-26.1; the minimum spanning tree-network belonging to this set is shown with figure A-26.2.

Consider distances between nodes disappearing; then nodes will join.
The sequence found in SORTLINKS -- the file with the distances between nodes sorted according to length -- determines in which sequence which nodes might be thought joining each other. When two (or more) nodes join, INTRANET creates a new entity, that is, a new (dummy-)node is constructed.

INTRANET results of such an 'interpretation' of the file are stored in matrices SM1 and SM2, as for example displayed by figures A-26.3 and A-26.4.
In the first column of SM1, row 8 is to be interpreted as:
node 8 joins node 10 making node (32+1).
Similarly, the second column shows node 6 joining node 7, and creating dummy-node 34.
The third column shows node 9 joining node 8 and node 10 in a dummy node 35.
Finally, nodes 1-32 are clustered.

Figure A-26.4 is a display of the matrix SM2, in which is kept track what dummy-nodes are the result of a clustering of other nodes.
Example 1: node (32+1)=33, the result of a joining of node 8 and 9.
Example 2: node (32+3)=35, the result of a joining of node 9 and dummy-node 33.

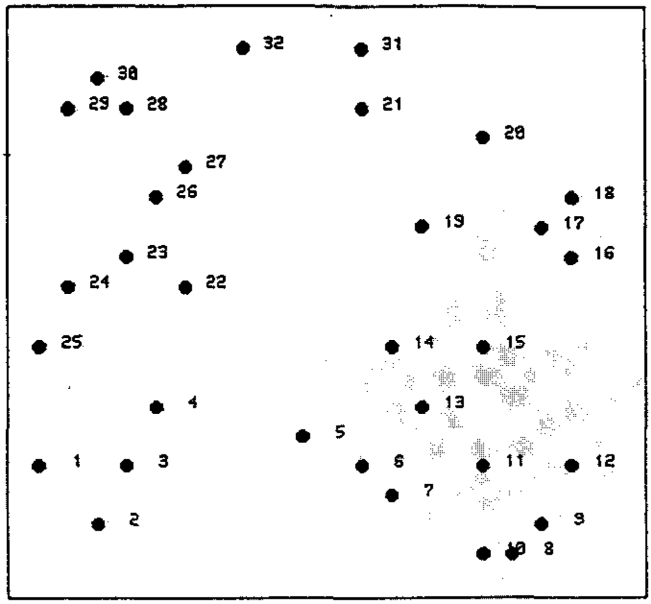



**Figure A-26.1. Example configuration with 32 nodes.**

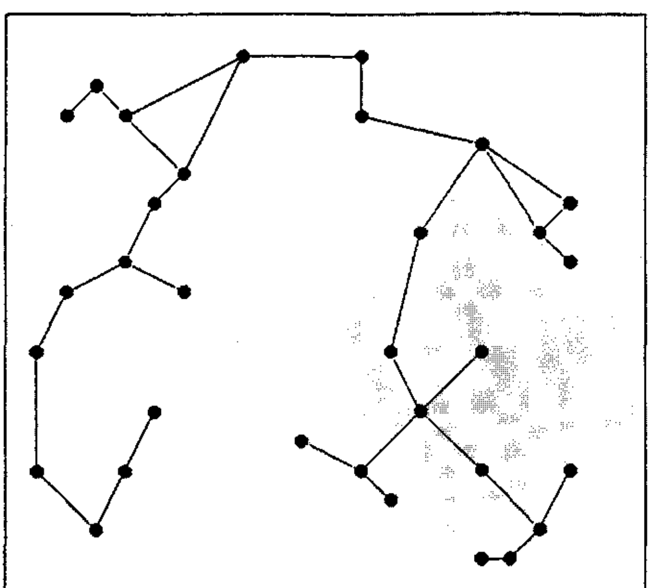


**Figure A-26.2. The minimum spanning tree belonging to figure A-26.1**

Figure A-26.3. Matrix SM1, showing the cumulative relationships between the nodes.

```
      node  32+
                 11111111112
      12345678901234567890
---------------------------
   1  ------------*---*--*-
   2  -------*----*---*--*-
   3  -------*----*---*--*-
   4  -------*----*---*--*-
   5  ----------*--*----**-
   6  -*--------*--*----**-
   7  -*--------*--*----**-
   8  *-*--------*-*----**-
   9  --*--------*-*----**-
  10  *-*--------*-*----**-
  11  -------------*----**-
  12  -----------*-*----**-
  13  ---------*---*----**-
  14  ---------*---*----**-
  15  -------------*----**-
  16  ---*-----------*--**-
  17  ---*-----------*--**-
  18  ---*-----------*--**-
  19  ---------------*--**-
  20  ---------------*--**-
  21  ------*----------***-
  22  --------*-----*-*--*-
  23  --------*-----*-*--*-
  24  --------*-----*-*--*-
  25  --------*-----*-*--*-
  26  -----*--*-----*-*--*-
  27  -----*--*-----*-*--*-
  28  ----*---------*-*--*-
  29  ----*---------*-*--*-
  30  ----*---------*-*--*-
  31  ------*----------***-
  32  -----------------***-
```

For a visualization of the dendrogram made, see figure A-26.5.

Figure A-26.4. Matrix SM2, showing the relationships between the nodes and the dummy-nodes

node 32+

```
             11111111112
    12345678901234567890
   ----------------------
 1  ||||||||||||*|||||||
 2  |||||||*||||||||||||
 3  |||||||*||||||||||||
 4  |||||||*||||||||||||
 5  ||||||||||*|||||||||
 6  |*||||||||||||||||||
 7  |*||||||||||||||||||
 8  *|||||||||||||||||||
 9  ||*|||||||||||||||||
10  *|||||||||||||||||||
11  |||||||||||||*||||||
12  |||||||||||*||||||||
13  |||||||||*||||||||||
14  |||||||||*||||||||||
15  |||||||||||||*||||||
16  |||*||||||||||||||||
17  |||*||||||||||||||||
18  |||*||||||||||||||||
19  |||||||||||||||*||||
20  |||||||||||||||*||||
21  ||||||*|||||||||||||
22  ||||||||*|||||||||||
23  ||||||||*|||||||||||
24  ||||||||*|||||||||||
25  ||||||||*|||||||||||
26  |||||*||||||||||||||
27  |||||*||||||||||||||
28  ||||*|||||||||||||||
29  ||||*|||||||||||||||
30  ||||*|||||||||||||||
31  ||||||*|||||||||||||
32  |||||||||||||||||*||
33  ||*|||||||||||||||||
34  ||||||||||*|||||||||
35  |||||||||||*||||||||
36  |||||||||||||||*||||
37  ||||||||||||||*|||||
```

continuation on next page

```
38  ||||||||*|||||||||||
39  |||||||||||||||||*||
40  ||||||||||||*|||||||
41  ||||||||||||||*|||||
42  |||||||||||||*||||||
43  |||||||||||||*||||||
44  |||||||||||||*||||||
45  ||||||||||||||||*|||
46  ||||||||||||||||||*|
47  ||||||||||||||||*|||
48  ||||||||||||||||||*|
49  |||||||||||||||||||*
50  ||||||||||||||||||*|
51  |||||||||||||||||||*
```

For a better understanding of these relationships, see the dendrogram figure A-26.5.
On the left side the eco-objects 1-32 are found. Going to the right, one sees numbers above 32; these are the dummy-nodes.
One may read f.i.: node 8 joins node 9, making node 33.
One may also read: node 9 joins node 33, making node 35.
At the end all nodes are clustered into one node; in the example this is node 52.

To be noted is that the dendrogram embodies, among other, the knowledge that the relevant distances within the cluster 40, made up of node 2,3 and 4 are equal.
This can be interpreted as: if it is possible to reach dummy-node 40 from node 3, all nodes within 40 are in reach.

With the use of matrices SM1 and SM2, each dummy-node can be translated into the constituing nodes.

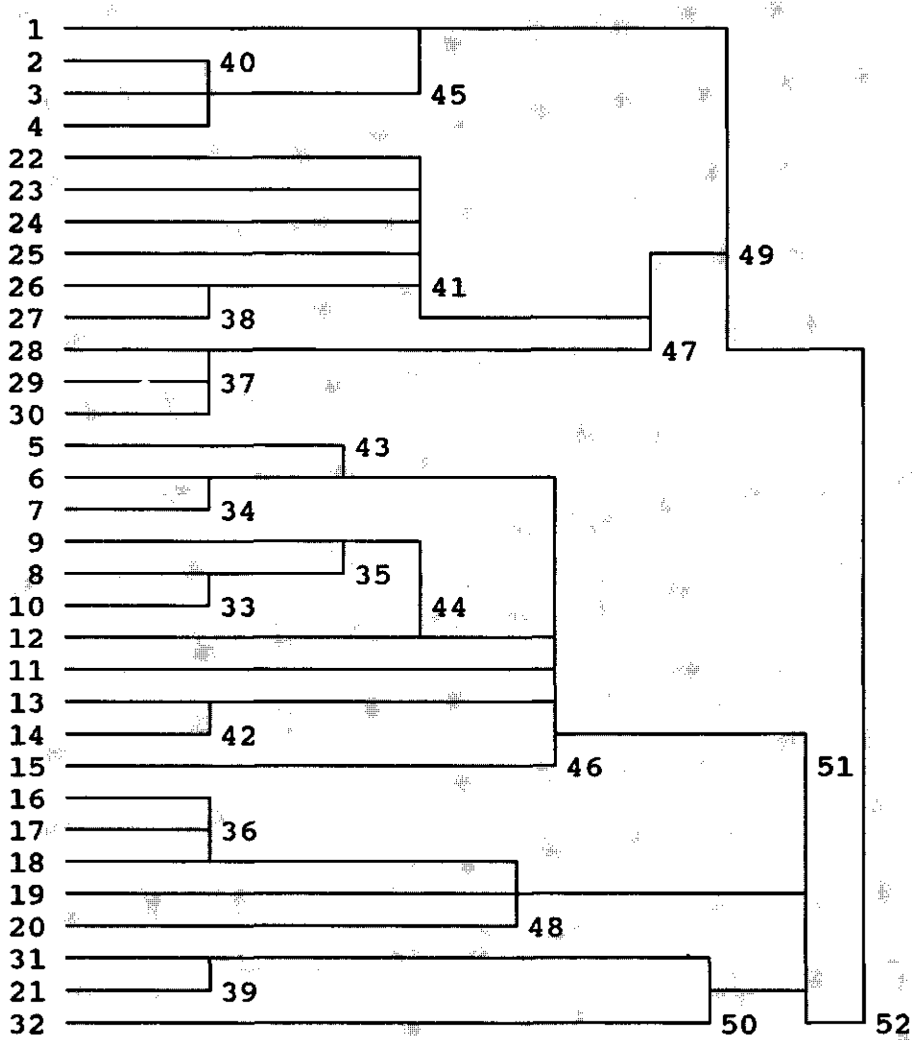



**Figure A-26.5.** Dendrogram, showing the relationships between the eco-nodes 1-32 of example A-26.1, by use of dummy-nodes 33-52.

## AN ADAPTED PROCEDURE FOR INCREASED CPU-TIME REDUCTION.

The surrounding polygon of bar-objects may consist of many nodes and display a very irregular shape.
The calculation procedures, described in chapter 5.6 (see also Appendix 28 and 29), therefore may require considerable CPU-time. The latter, however, can be reduced substantially by using a substitute-procedure, i.e. by using (where possible) a reduced set of nodes for each bar-entity.

See figure A-27.1 with an example object. The polygon embodying the object is made up of 28 nodes, of which 10 are protruding.
Rather than using all 28 nodes, it is possible to use only the subset of the 10 protruding nodes, as obviously shortest routes bypassing such bar-objects will not intrude within the 'reduced' shape.

It can be understood that a great reduction in CPU-time needed can be achieved.
In the case of figure A-27.1 a reduction from 28 nodes to 10 is possible. If for example the second object can also be reduced from 28 to 10 nodes, the number of distances to be calculated in both cases, is as follows:

| | | |
|---|---|---|
| original case: | 2.(28.28) = | 1568 distances |
| reduced case: | 2.(10.10) = | 200 distances. |

In general, a CPU-time reduction can be achieved of: $[N_1-(N_2/N_1)^2]\ .\ 100\%$

with $N_1$ = number of nodes in reduced figure
$N_2$ = number of nodes in original figure

Of course such a CPU-time reduction procedure is only possible when the two objects looked into, do not intertwine.
See figure A-27.2 for a situation in which the reduction procedure cannot be used.

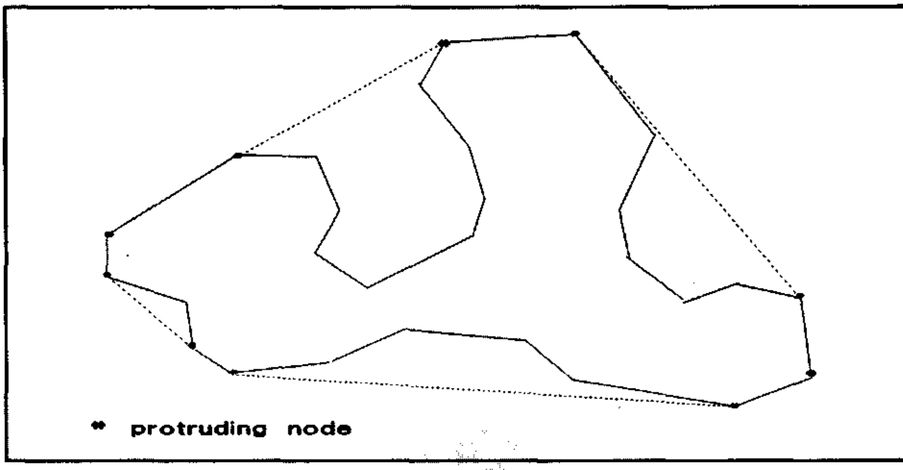



Figure A-27.1. An example configuration with protruding nodes and 'reduced' shape.

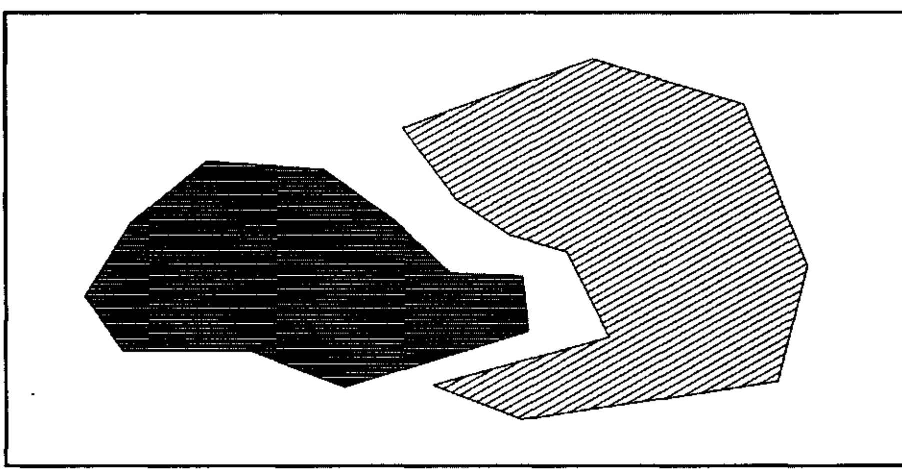


Figure A-27.2. An example configuration with intertwining objects.

## CALCULATING DISTANCES WITH ROUTE-OBSTRUCTIONS.

The procedure for calculating distances in situations with bar-objects obstructing the direct connection between habitat-areas, is based upon procedures where no bar-objects have to be taken into consideration.

With no bar-objects interfering, the following EE-procedure[1] can be used:

step EE1: make sets of eco-objects and start out with the first set;
step EE2: take the first node of the first eco-object in the given set and calculate the length of the perpendicular upon the first set of polygon-arcs[2] of the second eco-object in the given set;
step EE3a: calculate the length of the perpendicular upon the next set of polygon-arcs of the second eco-object in the set;
save the data belonging to the shortest perpendicular
step EE3b: [--]
step EE4: repeat step EE3 for all sets of polygon-arcs of the second eco-object in the set;
step EE5: repeat step EE2-EE4 for all other nodes of the first eco-object in the set;
step EE6: exchange the first eco-object in the set for the second and repeat steps EE2-EE5;
step EE7: the shortest perpendicular represents the shortest connection between the two eco-objects in the set;
step EE7: store data on all valid shortest connections;
step EE8: repeat steps EE2-EE7 for all sets of eco-objects.

In the above mentioned EE-procedure, no account has yet been given of the possible existence of bar-objects in between eco-objects.
If indeed barriers obstruct the 'direct connection', bypasses may have to be found and the distance related to the direct connection replaced by that of the shortest bypass. Therefore, the following sub-procedure, i.e. step, has to be included in the general EE-procedure.

step EE3b: disregard all connections that pass through barriers

Disregarding direct connections however, does not lead to new pathways, i.e. the alternative routing and distance to be coped with. A procedure for finding valid

---

1 EE refers to: Eco-object to Eco-object

2 Here a set of polygon-arcs is a set of upfollowing, directly linked nodes of the polygon embodying the entity.

routes has to be included.

**Eco to bar connections**
The following EB-procedure[3] has been developed:

step EB1: make sets of eco-bar combinations and start with the first set;
step EB2: take the first node of the eco-object in the set and connect the node with the first node of the bar-object[4] in the given set;
step EB3: store the connection if:
- no barriers have been found interfering
- no backward-crossing[5] through the eco-object occurs
- no forward-crossing[6] through the bar-object occurs

step EB4: repeat step EB2 for all other nodes of the bar-object in the set;
step EB5: repeat steps EB2-4 for all other nodes of the eco-object in the set);
step EB6: repeat steps EB2-5 for all other EB-sets.

See Appendices 29 and 30 for the crossing procedures.

**Bar to bar connections**
To determine the valid connections between bar-objects the following BB-procedure[7] is used in ECONET3:

step BB1: make sets of bar-bar combinations and start with the fist set;
step BB2: take the first node of the first bar-object in the set and connect the node with the first node of the second bar-object in the set;
step BB3: store the connection if:
- no barriers have been found interfering
- no backward-crossing through the first bar-object in the set occurs

---

3 EB refers to: Eco-object to Bar-object

4 It can be remarked that the bar-objects may consist of many nodes and the use of a reduced set may be called for. See App. 27.

5 An arc from a node A to B is considered crossing the object to which A belongs, if the line B-A onwards crosses the object to which A belongs.

6 A forward crossing occurs when the continuation of a line between node A-B crosses the object to which B belongs.

7 BB refers to: Bar-object to Bar-object

- no forward-crossing through the second bar-object in the set occurs

step BB4: repeat steps BB2-3 with all other nodes of the second bar-object in the set;

step BB5: repeat steps BB2-4 with all other nodes of the first bar-object in the set;

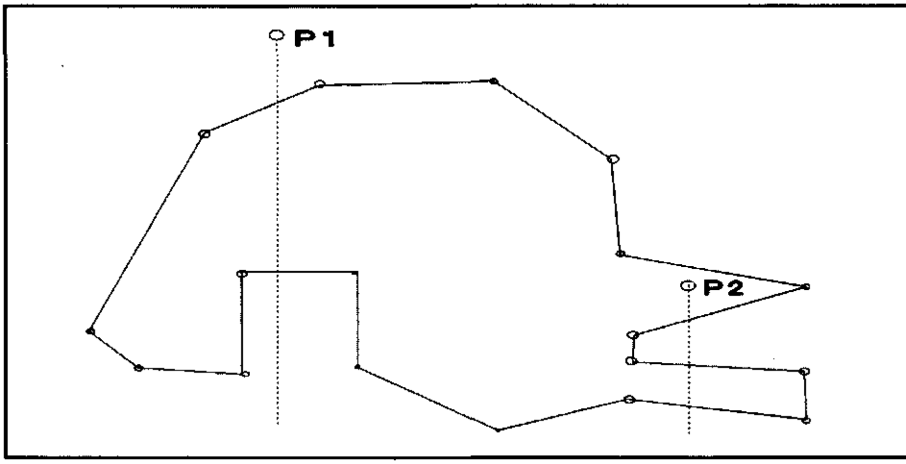
step BB6: repeat steps BB2-5 with all other bar-bar sets.

See Appendices 29 and 30 for the crossing procedures.

## THE LOCATION OF A NODE IN RELATION TO AN OBJECT.

Within ECONET a procedure is necessary to determine whether a node P lies within or outside a polygon.
To determine P's position, use can be made of the procedure by which a vertical line is drawn from P downwards and by determining the number of crossings with the polygon. With the number of crossings odd, P lies within the polygon, with the number even, P is found to be outside.

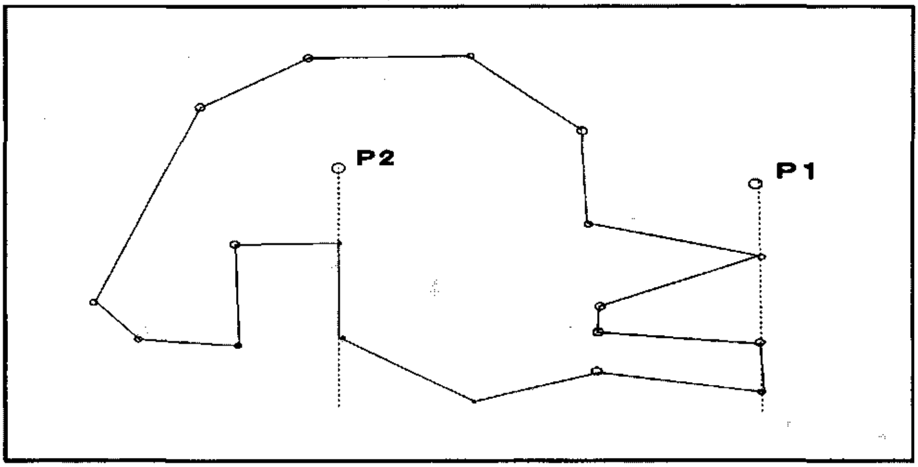
See figure A-29.1. As can be seen, the number of crossings from P1 downwards, is even, while that from P2 is odd.




o a node of the object
P internal/external point
| vertical through P downwards

Figure A-29.1. An example configuration with (vertical) lines crossing arcs.

In figure A-29.2, the second example, the situation is different; no crossings of arcs constituing the polygon, occurs. However, P2 lies within and P1 lies outside the object.
The conclusion has to be drawn, that a straightforward counting of crossings does not suffice. An adaption of the procedure is called for.

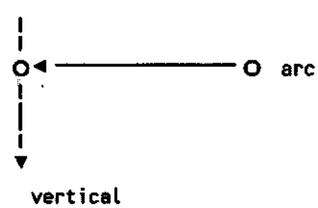



o a node of the object
P internal/external point
| vertical through P downwards

Figure A-29.2. An example configuration with (vertical) lines crossing nodes.

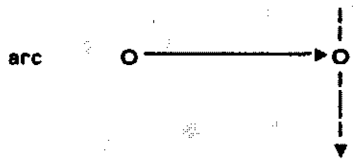
Consider a clockwise rotation through the arcs of the polygon (i.e. give each arc a direction attribute while tracking the polygon) and determine for each arc its position relative to the vertical through P downwards, then five types of crossing are to be accounted for:

(i) - the line from P onwards meets a node at the end of the arc, the arc coming from the left[8] and going towards this line:

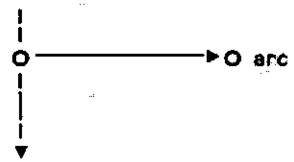



[8] It should be noted that any arc has two borders. To make a distinction between these two, the orientation of the arc is taken into consideration. Then 'left' is formally to be taken as left border.

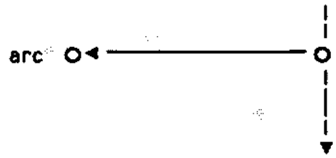
(ii) - the line from P onwards meets a node at the end of the arc, the arc coming from the right[9] and going towards this line:




(iii) - the line from P onwards meets a node at the beginning of an arc, the arc going towards the left:




(iv) - the line from P onwards meets a node at the beginning of an arc, the arc going towards the right:




(v) - the line from P onwards meets an arc in its own line orientation:


9 Similar to the formal description of 'left', the border 'right' is on the right side of the orientation of the arc.

ECONET uses the procedure fore-mentioned, making use of the distinction of type of 'crossing of arcs' as indicated above.

Use is made of a counter for the number of crossings and a counter for a dummy-variable:

| | |
|---|---|
| step 0: | set the crossing-counter to zero;<br>set the dummy-counter to zero; |
| step 1: | make a sequential set of arcs of the object;<br>make the line through P; |
| step 2: | determine whether the line from P onwards crosses the given arc;<br>if yes: count one for yes, and go to step 6;<br>if no : step 3; |
| step 3: | determine whether the line from P onwards crosses a node of the object;<br>if no : go to step 6;<br>if yes: go to step 4; |
| step 4: | if the arc situation is of the type (i), add 2 to the dummy-counter;<br>if the arc situation is of the type (ii), add 1 to the dummy-counter;<br>if the arc situation is of the type (iii), add 2 to the dummy-counter;<br>if the arc situation is of the type (iv), add 1 to the dummy-counter;<br>go to step 6; |
| step 5: | if the line from P runs along the arc, skip the counting and go to step 6; |
| step 6: | take the next arc and go to step 2 if there are still arcs left; otherwise go to step 7; |
| step 7: | count the value for the dummy;<br>if odd, add 1 to the number of crossings;<br>count the number of crossings;<br>if odd, then P lies inside; |

end of procedure.

Within ECONET a procedure is followed by which validity of connections between two objects, one being an eco-object, the other a bar-object, is determined. Valid connections are those of which neither the line, nor its extension either way, comes in conflict (i.e. crosses) with the objects.
See figure A-30.1 for some examples of valid and non-valid connections.

To determine whether conflicts occur, a similar procedure as explained in Appendix 29 can be followed. The similarity lies in the fact that a line is drawn, and the number of crossings of the line (or its extension) with an object counted. The dissimilarity lies in the fact that the line drawn, most often is not vertically oriented.

Connections AG and EJ are valid; the others are non-valid.
The connection CK for example is not valid, the extension CK forwards showing a conflict with object II, while CK-backwards runs into the eco-object (I) itself. The extension of DJ backwards, also shows a conflict with the eco-object.
The line FJ is an example of a situation where there is no conflict with the bar-object (II) but having a so-called internal conflict (with object I). FJ crosses DE.

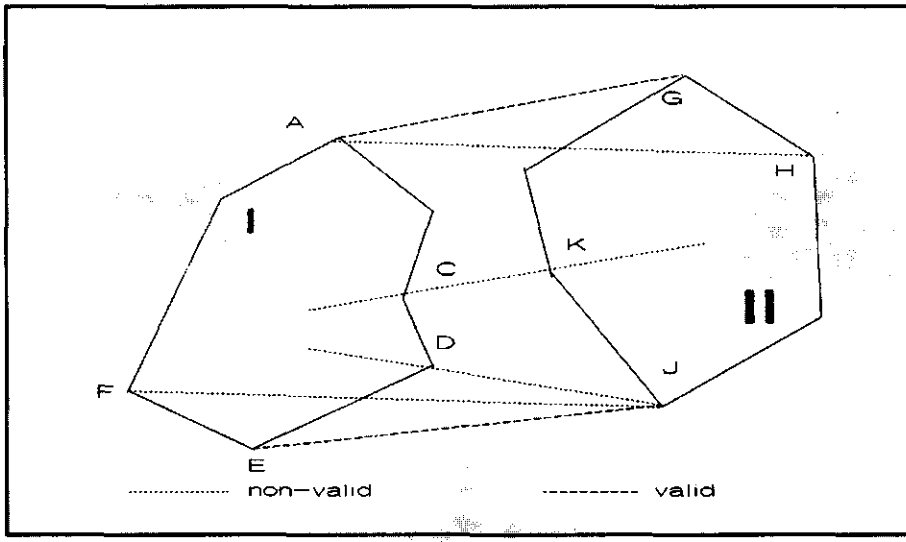



Figure A-30.1. Examples of valid and non-valid connections.

The general procedure for the determination of valid connections between a node A of an eco-object I and the nodes $P_i$ of a barrier, object II, is:

step 0: set a counter to zero

step 1a: make a sequential set of nodes $P_i$ of the bar-object;

1b: make a sequential set of arcs of the bar-object;

1c: make the connection between node A and $P_i$ ;

step 2: determine whether the line through A and $P_i$ crosses the arc of the bar-object of which $P_i$ is the beginning;
if yes : signal a conflict and continue with step 6;
if not : go to step 3;

step 3: determine whether the line $AP_i$ crosses[10] nodes of the bar-object:
if not: go to step 6;
if indeed: go to step 4;

step 4: if the arc situation[11] is of the type (i), add 2 to counter;
if the arc situation is of the type (ii), add 1 to the counter;
if the arc situation is of type (iii), add 2 to the counter;
if the arc situation is of type (iv), add 1 to the counter;
go to step 6;

step 5: if the connection $AP_i$ meets an arc of bar-object in its line of direction, skip the counting and go to step 6;

step 6: if there are still arcs left in the series made in step 1b, upgrade i and continue with step 1c; otherwise go to step 7;

step 7: read the counter;
if the number is odd, the connection is non-valid;
go to step 8

step 8: end of procedure for node A of object I.

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10

Into consideration is to be taken not only the section $AP_i$ but also the forward and backward extensions of this section.

11

See Appendix 29.