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REPORT

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WP2
Description and Validation of Technical Tools

D5 – Guidelines for the use of technical tools

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CARE – W

Computer Aided REhabilitation of Water networks.
Decision Support Tools for Sustainable Water Network Management

WP2: Description and validation of Technical tools
WP2.3: Guidelines for the use of Technical Tools[1]

Deliverable D5

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[1] *Reference*:
EISENBEIS P., POULTON M., LAFFRÉCHINE K., LE GAUFFRE P. (2004) *CARE-W: WP2 – Description and validation of Technical tools D5* – Guidelines for the use of Technical Tools. CARE-W (Computer Aided Rehabilitation of Water networks), EU project under the 5th Framework Program, contract n°EVK1-CT-2000-00053. Cestas (F): Cemagref, January 2004, 26 p. + Appendices (68 pages)

1 Introduction

1.1 CARE-W general objectives

CARE-W project aims at developing methods and software that will enable engineers of the water undertakings to establish and maintain an effective management of their water supply networks, rehabilitating the right pipelines at the right time. The results shall be disseminated as a manual on Best Management Practice (BMP) for water network rehabilitation.
This project is organised in the following Working Packages (WP):

- WP1: Construction of a control panel of performance indicators for rehabilitation;
- WP2: Description and validation of technical tools;
- WP3: Elaboration of a decision support system for annual rehabilitation programmes;
- WP4: Elaboration of long-term strategic planning and investment;
- WP5: Elaboration of CARE-W prototype;
- WP6: Testing and validation of CARE-W prototype;
- WP7: Dissemination;
- WP8: Project management.

1.2 Work Package 2 objectives

Cemagref is responsible for WP2, which is divided in three Tasks. This report refers to the Task 2.2. "Test and validation of technical tools".
This task has several objectives:

- to test and compare the models on several water networks, that have different characteristics (size, geographical specificities, hydraulic conditions, material, type of data, maintenance data, …),
- to have a critical look on the models, with the aim of validating and fitting them,
- to improve and make their utilisation easier,
- to help to use the tools (procedure, data, tool to be used).

1.3 Objective of this report

This report aims to help the end-users to use the Technical tools proposed in Care-W. This tools are presented in *(Eisenbeis et al, 2002a)*. For each type of tools, two type of information are described:

- the data, and the way to collect them,
- the tools and proposals to choose the tool according to the service.

2 FAIL tools

The *FAIL* tools of *CARE-W* are tools for assessing and predicting the failure rates of water distribution pipelines. This information can then be used as criteria in the *Annual Rehabilitation Programme* (*Care-W_ARP*). These tools are:

- *Care-W_PHM*, elaborated by Cemagref,
- *Care-W_Poisson*, elaborated by INSA-Lyon.

Detailed information regarding these tools is available in the *CARE-W D4 Report* (ref??).

2.1 Description of the data

FAIL tools are statistical tools that need data concerning the pipes (or segments) and their environment, as well as their associated failures. The two types of data file (segment description and maintenance data) are described below. It is advised to keep a separate text document to accompany each file, describing the data and other relevant information.

2.1.1 Segment description data

This file can include all the pipes in a network or just those in a specific zone, for which maintenance data have been recorded for some years. The definition of the pipe will comply with that used in the Water Utility databases or GIS .

The description of the pipe is proposed in 3 facets:

1) Identification of the pipe,
2) Description of the characteristics of the pipe itself,
3) Description of the pipe environment.

The data are described in Table 2.

2.1.2 Maintenance data

Maintenance data describe the failures, their occurrence date and other information. **Table 1** presents these data, which are in maintenance description files.

Table 1: Maintenance data

		Mandatory / Optional	Quantitative / Qualitative	Type of data (Numeric or alphanumeric)	Unit (if Quantitative)	Description
M1	ID or ID1, ID2, …, ID*n*	M	Qual	Alpha		Variable or set of *n* variables that identify univocally the segment (one and only one per segment)
M2	FDAT	M	Quant	Date	Day (DD/MM/YYYY)	date of failure
M3	FTYP	O	Qual	Alpha		Type of failure
M4	FCAU	O	Qual	Alpha		Cause of the failure
M5	RTYP	O	Qual	Alpha		Type of repair
M6	other	O				

Table 2: Segment descriptive data

			Mandatory / Optional	Quantitative / Qualitative / Both	Type of data (Numeric or alphanumeric)	Unit (if Quantitative)	Description
Segment Identification	I1	ID or ID1, ID2, …, ID*n*	M	Qual	Alpha		Variable or set of *n* variables that identify univocally the segment (one and only one per segment)
	I2	STR	O	Qual	Alpha		street, road or locality
	I3	AREA	O	Qual	Alpha		area (municipality or region or zone),
	I4	GEO	O	Quant	Alpha	'	Geodetic coordinates
Segment characteristics	C1	LENG	M	Quant	Number	m	Segment length
	C2	DIAM	M	Quant	Number	mm	Segment diameter
	C3	MAT	M	Qual	Alpha		Segment diameter
	C4	INST	M	Quant	Date	Day (DD/MM/YYYY) or Month (MM/YYYY) or Year (YYYY)	Date of installation
	C5	REPL	O	Quant	Date	Year (YYYY)	Date of replacement of the segment
	C6	REHA	O	Quant	Date	Year (YYYY)	Date of rehabilitation of the segment
	C7	IPRO	O	Qual	Alpha		Internal protection
	C8	EPRO	O	Qual	Alpha		External protection
	C9	JOIN	O	Qual	Alpha		Type of joint
	C10	DEPT	O	Quant	Number	m	Depth
	C11 to C15	Other	O	Quant (Qual if suffixed with $)			User defined
Segment environment	E1	SOIL	O	Both	Alpha	mΩ	Type of soil (or soil resistance)
	E2	TRAF	O	Both	Num. Or Alpha	Number of vehicles/time or class of traffic intensity	Traffic in the street or road
	E3	LOCA	O	Qual	Alpha		Location of the segment in the street (under sidewalk or pavement)
	E4	BEDD	O	Qual	Alpha		Type of bedding
	E5	PRES	O	Quant	Number	mPa	Pressure in the segment (static max. or dynamic min. or max. difference between static and dynamic)
	E6 to E10	Other	O	Quant (Qual if suffixed with $)			User defined

2.2 File format

The name of the files must be as follows for the city called "City":

- City_sdf.txt (or City_sdf.csv)
- City_mdf.txt (or City_mdf.csv)

The two files "sdf" and "mdf" are described below. These are files in "Text" format, with values being separated by a semi-colon ";". This format of file is identical to the format "csv" in *Excel*.

2.2.1 Segment description file (City_sdf.txt)

The first line provides the name of the city. The second line provides the name of the variables (I1, E7, C4,…). The other lines contain the variables' values for each pipe.

An example of an "sdf" file is presented below (Figure 1).

```
City_sdf; ; ; ; ; ; ; ; ;
I1;I3;C1;C2;C3;C4;E2;E3;E5;E8$
439;;15;100;INC;1989;SupL;Inconnu;43;Neant
452;;133;100;INC;1989;SupL;Autres;43;Neant
454;;43;100;INC;1989;SupL;Autres;43;Neant
455;;152;100;INC;1989;SupL;Autres;43;Neant
456;;10;100;INC;1989;SupL;Autres;43;Neant
457;;4;100;INC;1989;SupL;Autres;43;Neant
459;;123;100;INC;1989;SupL;Autres;43;Neant
461;;123;100;INC;1989;SupL;Autres;43;Neant
463;;34;150;INC;1990;SupL;Autres;44;Neant
465;;50;150;INC;1990;SupL;Autres;44;Neant
466;;103;200;INC;1990;SupL;Inconnu;44;Neant
467;;10;200;INC;1989;SupL;Trottoir;43;Neant
470;;3;250;INC;1989;SupL;Autres;43;Neant
474;;20;250;INC;1989;SupL;Autres;43;Neant
475;;6;500;INC;1989;SupL;Autres;43;Neant
```

Figure 1 : Example of an "sdf" file

Several rules must be respected:

1. **No fields greater than 15 characters in length**
2. **No fields with non-alphanumeric values (e.g. &,-,?,/ are not permitted)**
3. **No fields with a string of 9s**, e.g. 999 or 9999 (reserved value used by PHM)
4. **If an installation date is unknown, is it advisable to give it a sensible, early installation date, suitable for the material type**, preferably before the start of the "observation period" (user-defined start of analysis period)

2.2.2 Maintenance data file (City_mdf.txt)

The first line provides the name of the city. The second line provides the name of the variables (M1, M2,…). The other lines contain the variables' values for each failure.

An example of an "mdf" file is presented below (*figure 2*).

Figure 2 : Example of an "mdf" file

```
City
M1;M2;M3;M4;M5
D456;05/01/1985;Crack;unknown;replace1m
D123;03/12/1954;pit;corrosion;unknown
```

2.3 Comments on data

2.3.1 Pipe identification data

These data allow the identification of the pipe.

ID: This value is indispensable. It will allow the *Fail* tools to make the link between the pipe (sdf file) and the failure (mdf file). The ID may derive from the company GIS. In this case keeping the same value will allow results to be fed back to the GIS after the analysis. If the ID does not exist (for instance because of no GIS), it is necessary to create it. In this case, it is recommended to create a value that indicates the pipe's geographical position. The ID could include the zone, for instance.

STREET: This variable is useful during data collection, notably if data comes from paper records. It can facilitate the linking of failures and pipes.

AREA: This provides a spatial variable to include in the analysis. A particular zone, may have a higher (or lower) failure risk, because of specific conditions in the area.

GEODETIC COORDINATES: The geodetic are useful to implement data in a GIS.

2.3.2 Pipe characteristics data

Diameter: The diameter is a major variable; previous studies have shown that diameter is almost always statistically significant. Generally, the higher the diameter is, the lower the failure probability. In some cases, the diameter can be correlated with material. For instance, in the case of New York City, where large diameter mains are often steel. It is necessary to check this correlation, if the result seems illogical.
The diameter can be studied as a quantitative variable (also log of diameter), or a qualitative variable, with one or more modalities according to the values. For instance, two classes can be created : class1 (up to 150 mm), class2 (greater than 150 mm).

Length: The length is also a major variable and almost always significant. Usually, the greater the length, the higher the failure risk. It is studied as a quantitative variable (often as log of length).

Material: The material is also an important variable. It can be included in the analysis in two ways. The first way is to perform a separate analysis for separate material types, e.g. one analysis for Grey Cast Iron, one for Ductile Cast Iron, one for PVC etc. Often two or three material types represent over 95% of all the pipes. In this case, the less common materials should not be analysed alone, because of the insufficient number of individual pipes and failures. The second possibility is to make an analysis with the whole sample (including all the materials), by including the material as a qualitative variable.

In some cases, the material is described very accurately and contains a lot of modalities (for instance a material may be subdivided according to the joint type, the installation date and/or the internal or external protection. This can cause problems due to too few pipes per category. It is therefore advised to group such materials and to limit the number of modalities (5 or 6 maximum).

Installation date: This value can be used in several different ways. It can be transformed into a qualitative variable: in this case the installation period will be studied (and not the precise age) of the pipe. Previous studies have indeed shown, that in many cases, pipe laid in the period just after the 2nd world war have a higher failure risk than the pipes laid just before. The other way is to use this value as a quantitative variable (for instance the age of the pipe at the beginning of failure observation). In this case, the age will be studied, even if the installation period will have an influence on the results.

In *Care-W_Poisson* this value is not indispensable. In *Care-W_PHM*, the installation date is essential, or at least an indication of the date (notably if the pipe was laid after the beginning of failure observation.)

Other pipe characteristics can also be useful, but rarely exist in databases. These include:
- Type of joint,
- Internal or external protection,
- Depth of installation.

The collection of these values, either during pipe installation or maintenance, could be easily made and used in future analysis.

2.3.3 Pipe environment data

These data characterise pipe environment, i.e. all data external to the pipe or internal data.

External environment data :

- Soil Type: The soil can be characterised in two ways: its chemical properties and its mechanical properties. In the first case, the data will provide information concerning the risk of corrosion of the pipe. This can be quantitative (soil resistivity) or qualitative (type of soil, soil humidity). In the second case, the data will provide information concerning the risk or movement of the soil, which can lead to breaks.
- Traffic: This value is either qualitative (number of vehicles by day or number of trucks per day, etc…) or quantitative (type of road, highway, main road, etc…).
- Pipe location

This variable will inform if the pipe is under the roadway or under the pavement.

- Trench type

This variable describes the type of the trench, where the pipes were laid, and notably the quality of the material used for the trench:
- original material,
- sand,
- …

- Pressure

This quantitative variable describes the service pressure in the pipe. Several possibilities can be chosen:
- static pressure (i.e. highest pressure),
- dynamic pressure,
- variation of pressure in the day.

Other environmental data can be proposed according to the data existing in the service and also according to failure risk factors known by the service. The variables below are those existing in previously studied water utilities:
- Water quality (qualitative variable describing the origin of the water),
- Electric currents existing in the soil (caused by railways, electric lines, tramway).

2.3.4 Failure data

- **The length of the period of failure recording**

In principle it is necessary to have the longest period as possible. It is desirable, if all the failures have been directly recorded in a computer database or GIS for this period. Such records are generally considered to be accurate.

If though, part of the failure record exists on paper (and is subsequently transferred to the database), it is necessary to be sure of the reliability of these paper records. Indeed it has been noticed in previous studies, that failures records on paper are not always complete and accurate.

In other words, it is better to have a short, but reliable, record period, than a longer, but less reliable period. For large water utilities, a 3-year record period could be sufficient to make a suitable statistical analysis.

- **ID:**

This value is the pipe ID, where the failure occurred.

- **Failure date:**

This value is obligatory. It represents the date of the day when the failure occurred. If only the month is known, a solution is to provide the following date : 15/MM/YYYY . By the same way, if only the year is known, it is proposed to give the following date : 01/07/YYYY . Of course in this case, the data will be less reliable.
For Care-W Poisson, the year can be sufficient.

In many cases, failures at the same date and concerning the same pipe have been recorded in the database. In this case there are two possible reasons:
- the same failure has been accidentally recorded twice,
- two failures did really occur on the pipe, the second one being due to a bad repair of the first failure.

In the two cases, it is proposed to eliminate one of the failures.

The other facultative data are :

- Failure type :
This represent breaks, leaks or leaks on joint . This allows the programs to differentiate failures (all failure type) and breaks, for the calculation of PFR (Predicted Failure Rate) and PBR (Predicted Break Rate).
- Failure cause :
This value can differentiate failures caused by other works from failures caused by the water network.
- Repair type.

These previous data are rarely collected now, but they could be useful in the future to improve the analysis. For instance, it is obvious that a leak on a joint will not have the same cause as a break on the pipe.

2.4 How to collect the data?

Several scenarios may arise according to the existing pipe data :

- Pipe Data exists on paper,
- Data concerning pipes exists on GIS (or data base).

Notice that if there is no existing corresponding pipe data, the failure data cannot be considered because it is absolutely necessary to have a minimum knowledge of the pipe (length, diameter, material).

2.4.1 Pipe data exists already on paper

In this case, it is first necessary to record these data in a data base (or in a GIS, if appropriate). Each link must be identified by homogeneous variables (at least diameter, length, material or installation date). Generally a link is defined at street scale.

If the pipe has been repaired, with a short part (1 meter for instance) replaced by another material, it is advised not to create 2 or 3 links, but to keep the pipe, by noticing the number of past failures.

In some cases, variables (mainly environmental) can be suspected to influence the failure. In this case it is advisable to perform a specific study to collect these data, because they will be very probably estimated as significant.

Other available data that can exist on several papers in the water utilities (notably installation date) can be used to complete this data base. If data are missing, they can be recorded bit by bit, by collecting the data when repairing the pipe.

Two alternatives are then possible concerning the failure data, that must be included in the GIS or data base:

- No failure data : in this case it is advised to record the data in the format defined above.
- Existing failure data : the main task will be to link each failure to the pipe (same ID for the pipe and the failure). Sometimes it is difficult to define the pipe, because a pipe with, for example, the same diameter and same material may have a different installation date. There is often imprecision concerning several variables, such as the diameter, the street or the material. This could lead to the elimination of failures and increase the risk of errors in the statistical analysis. If this imprecision seems to great,

it is advised to abandon bit by bit these data, replacing them by new and accurate recorded data.

To avoid the risk of inaccuracies, it is advised that the repair workers, who will notice the information concerning the pipe and the repair must use very specific forms, with "closed" question, to avoid possible wrong interpretation. An example of such a form is presented in Figure 3. It is not exhaustive and can be different according to the service.

2.4.2 Pipe data exists in Data-base or GIS

The first task is to check missing pipe data, such as diameter, material and installation date, and do as much as possible to complete them.

After completing these data, as in the previous case, failure data must be collected. If they don't exist in a database or GIS, this is performed in a similar way as previously.

If they have already been recorded in the database or GIS, it must be checked that each failure is linked to a pipe by an ID. If not, this ID must be created in each pipe or failure file.

1.5 Choosing which tool to use?

Two tools calculating the number and failure rates exist in CARE-W: PHM and Poisson tools.

To summarize, their objectives are slightly different :

- PHM makes a forecast of future failure rate or number over a defined period (5 or 10 years), after evaluating the influence and statistical significance of the variables.
- Poisson computes past failure rate (based on several possible periods) per category (defined among expertise or statistical tests) and pipe.

Poisson utilisation can be very simple, while giving satisfactory results in term of benefit:

- Firstly, the pipe categories must be chosen according to several variables. The step consisting of testing variable statistical significance (using statistical software) is facultative.
- Secondly the length of the failure record period must be chosen and the failure rate is directly calculated for each pipe and each category.

PHM utilisation is a little more complicated:

- First (facultative step) variables can be adapted to PHM model and the number of models, according to the number of previous failures must be chosen. It means that the variables can be modified to facilitate their study.
- Secondly, variable significance must be studied for each model. An advice system is proposed.
- Finally when all significance variables have been defined, the forecast can be computed for each pipe.

1 – FAILURE LOCATION

Municipality		**Date**			**If no number, Distance (m) …………. from …………… (see scheme)**
Street (or location))		**N° in the street**		❑ **even side** ❑ **uneven side**	

2 – GENERAL DESCRIPTION OF THE PIPE

Pipe diameter (mm):		**Pipe material :**	❑ Steel ❑ Asbestos-Cement ❑ Ductile Cast Iron ❑ Concrete	❑ Grey Cast iron ❑ PE ❑ PVC ❑ Other : ……….
Installation date (even approximate)				

3 – DESCRIPTION OF THE REPAIR

Failure type (choose one or more)	**Presumed cause of the failure**: (choose one or mores)	**Repair type :** (choose one or more)
❑ Clean break ❑ Longitudinal break ❑ Crack ❑ Hole(s) Number : Diameters : ❑ Joint ❑ other : ……………..	❑ unknown ❑ Third party ❑ Internal corrosion ❑ External corrosion ❑ Field movement ❑ Overpressure ❑ Other :……………….. …………………………	❑ 2 joints + pipe : material : …………….. length (m):…………… ❑ Repair sleeve ❑ Changing joint ❑ Dulling joint ❑ other : …………………

4 - DESCRIPTION OF THE PIPE AND ITS ENVIRONMENT

THE PIPE

Internal protection :	**External Protection**		**Type de joint :**
❑ None ❑ Cement ❑ Epoxy ❑ Bituminous ❑ Other : ……….	❑ None ❑ PE/ Polypropylene ❑ Zinc ❑ Bituminous ❑ Cathodic ❑ Other : ……….		❑ Lead Joint ❑ Mechanical joint ❑ Stuck joint ❑ Rubber Joint ❑ Soldered Joint ❑ Sleeve
Depth (m) :	…………………	**Pipe location :**	❑ Under pavement ❑ Under road ❑ Other : ……………..

PIPE ENVIRONMENT

Pipe bedding :	**Field of the soil** :	**Soil condition :**	**Traffic** :
❑ None ❑ Sand ❑ Crushed limestone ❑ natural soil ❑ Rock, stone ❑ Other :…………..	❑ Rock ❑ Sand, gravel ❑ Clay ❑ Silt, peat ❑ Backfill ❑ Marl ❑ Other : …………	❑ Water table ❑ Dry ❑ Wet ❑ Sodden ❑ Frozen ❑ Thaw ❑ Other : ……….	❑ None ❑ Weak (service roads) ❑ moderated (main roads) ❑ Important(trunk road, trucks, buses, …)

Figure 3: Example of form to describe the failure and the pipe *(Eisenbeis et al, 2002b)*

Poisson and PHM results are very similar. However, in PHM the statistical test is integrated into the tool and has been adapted to make it easier to use. Consequently the effect of considering a variable in the database is directly known. Confidence intervals are also given by PHM.

For the two tools, the knowledge of installation date is indispensable. However, if the date is not known, a date, before the first failure observation date, can be allocated.

These two tools are complementary and do not require the services of an experienced statistician for their use.

Tests made in the Care-W project *(Eisenbeis et al, 2003)* have shown that a simple classification of the pipes according to their past failure numbers could also give interesting results to classify pipe to prioritise. (Cf. Figure 4, below). However it has been noted that only 10 to 15 % of the pipes have broken in the past. Consequently with this kind of classification all the pipes without previous breaks (at least 80 to 85 %) can not be classified. The same figure shows that without a model (yellow curve) it is not possible to classify pipes beyond 10 to 15%, contrary to Poisson and PHM Model. This is especially so for services that have a short recording period time (Cf. Figure 5).

Without Poisson and PHM models, it is then difficult to use the Failure Rate as parameter for Care-W_ARP. An example of a criterion used in the multi-criterion decision support software (CARE-W_ARP) shows that the assessment of the failure rate is important not only for high values but also for low values.

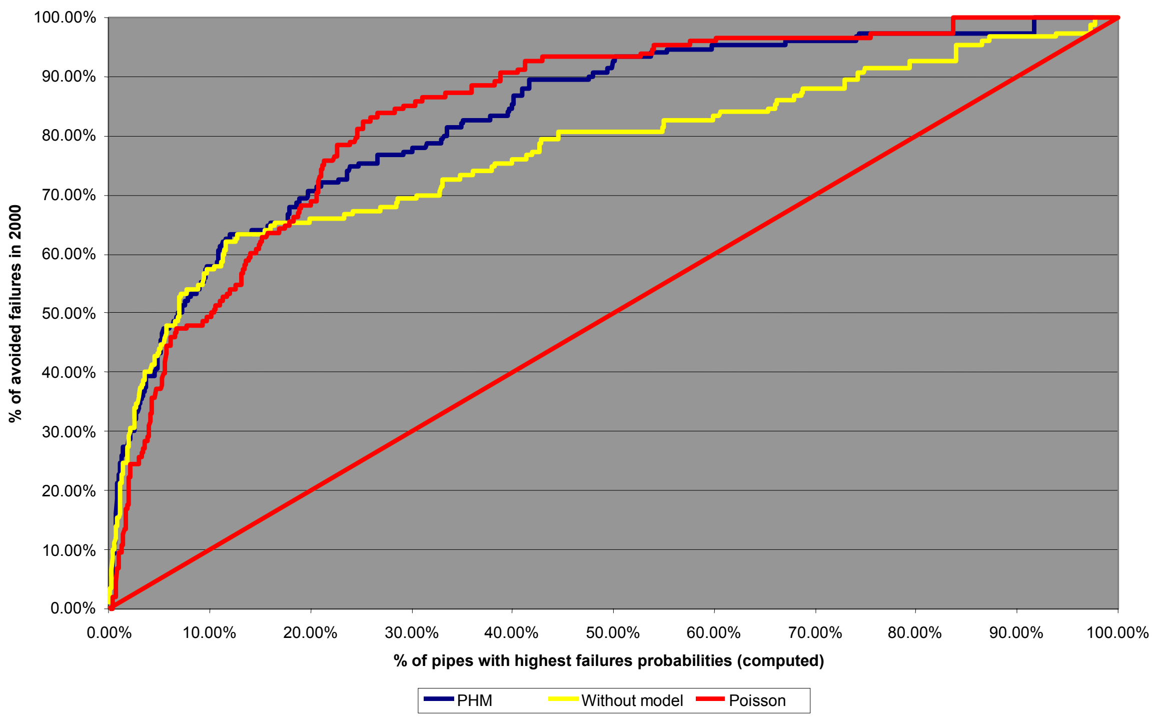

Figure 4 : Benefit index of Care-W PHM, Care-W_Poisson and without model (Trondheim) *(Eisenbeis et al, 2003)*

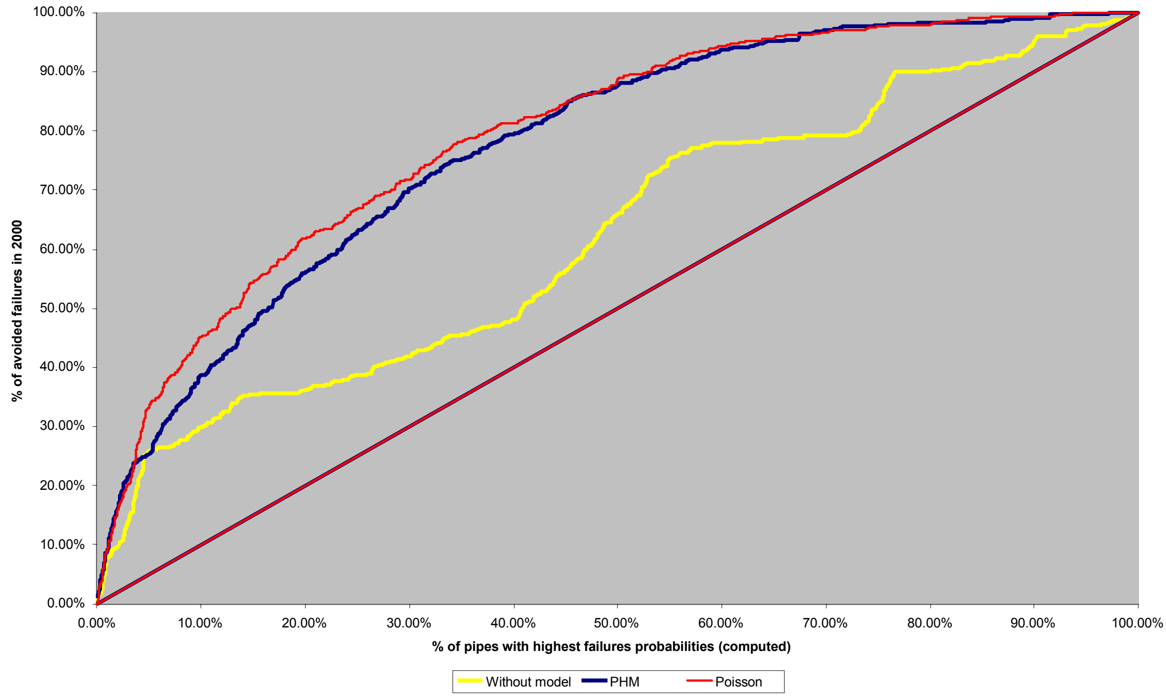

Figure 5 : Benefit index of Care-W PHM, Care-W_Poisson and without model (short record time, Trondheim) ***(Eisenbeis et al, 2003)***

As the consequences of a failure may be much higher for some particular pipes, rehabilitation of pipes with low failure rates may appear as priority projects within a preventive approach.

Criterion PWI (Predicted Water Interruption) is calculated as follows:
PWI = PBR . EDI . NPS
With:
PBR: Predicted burst rate
EDI: Expected duration of interruption (hours)
NPS: Number of people supplied by the link

Figure 6 (Reggio Emilia case study) shows that a pipe with a low burst rate (e.g. 0.02 bursts/100m/year) may appear as a highly ranked rehabilitation candidate, similar to other pipes with a high burst rate (e.g. 0.5 bursts/100m/year).

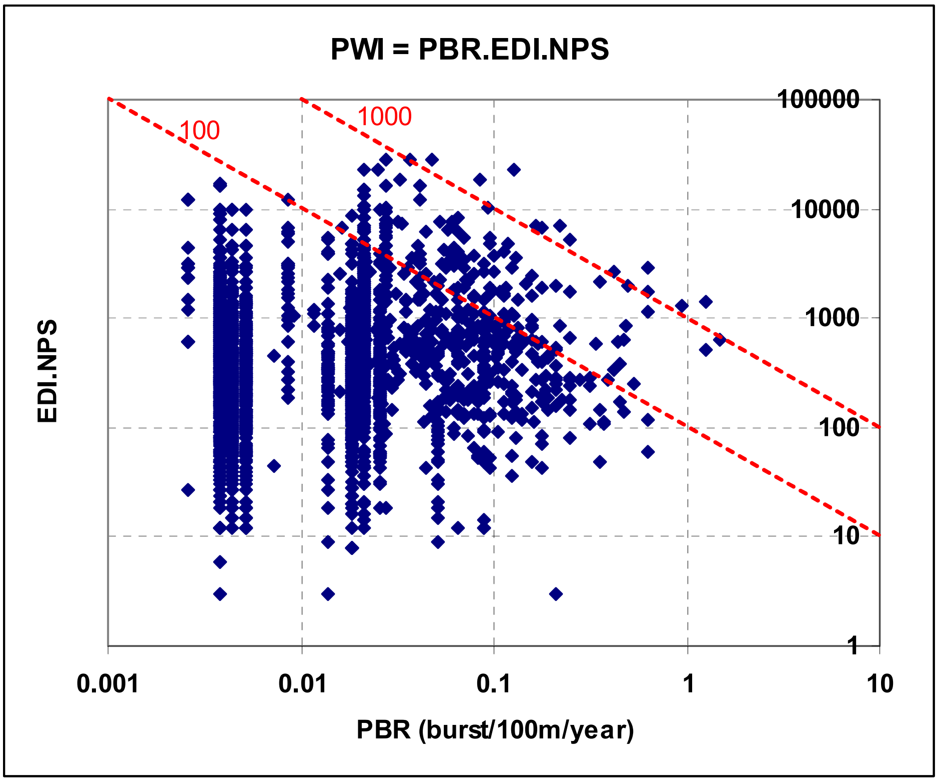

Figure 6: Interest of considering pipe with low predicted burst rate

Table 3 summarises the different aspects of CARE-W PHM and CARE-W Poisson and thus helps the user to choose the most appropriate.

Table 3: Characteristics of Care-W_PHM and Care-W_Poisson

	Poisson	**PHM**
Pipe Data	Indispensable : diameter and material, installation date (approx.) Useful : other environmental pipe data	At least, diameter, material, installation date (approx.) Useful : other environmental pipe data
Failure Data	2-3 years	2-3 years
Objectives:		
- variable significance test	Yes, with statistical software	Yes
- Failure rate by category	Yes	Not directly
- Failure rate by pipe	Yes	Yes
- Forecast	No	Yes

3 Rel tools

3.1 The data

Data to be used in Rel Tools must come from a hydraulic model, that has already been calibrated. The Rel tools are indeed not hydraulic models, that are useful for calibration.

These data are in two possible format :

- "Epanet" format for Aquarel and Relnet,
- Text Format, (two files) for Failnet-Reliab.

Input Epanet files can be either specific Epanet file format (.NET) or Text files (.INP) .

Concerning Failnet-Reliab Text files, two files have been created :

- one concerning the description of hydraulic links (hlf files),
- one concerning the description of the nodes (ndf files).

(Cf. format description in appendix).

These files describe :

- consumption nodes : elevation, consumption, required pressure, node importance (facultative),
- Tanks : water level, minimum level, maximum level, volume **(Aquarel)**,
- Water source : water level,
- Hydraulic links : length, diameter, roughness, **failure rate** (Aquarel, Failnet-Reliab)
- Pumps (characteristic curve, Aquarel, Relnet).

Some differences exist caused by the characteristics of the software :

- Aquarel can make a calculation over 24 hours, that means that it will need the volume of the tanks, to verify that they are not yet empty, after a break.
- Aquarel and Failnet-Reliab use failure rate to calculate the unavailability duration of the pipe. Additional data are useful: the Mean Time To Repair, that is the duration of the repair between the beginning of the break and the bringing back into service. This duration can vary according to the diameter for instance.
- Failnet-Reliab can not currently include pumps. This problem can be overcome by changing the origin data and replacing these pumps by increasing artificially the water level, for instance. .

Lastly, data determining the calculation hypothesis are necessary. These are :

- the definition of required pressure for all the nodes,
- the definition of Mean Time To repair (eventually according to diameter).

3.2 How to collect the data?

The collection is the same as for hydraulic modelling. The way to collect data for these models and create a model will not be explained in this part.

An important point will be however discussed: this concerns the type of element to consider and the fact that the hydraulic link can be different than the "statistical" segment (sdf file).

Indeed for statistical analysis of failures and also for the prioritisation of pipes to replace, the segment to be considered is a pipe, generally in the same street, with homogeneous data: same diameter, material, etc…

Concerning the hydraulic reliability tools, the basic element (i.e. the link used in hydraulic modelling) is a pipe linking two nodes, a node representing a crossing of two or more pipes, a consumption node, a tank or a water source.

In Figure 7 and Figure 8, these two points are presented. For instance the segment A, used for failure analysis, is represented in Hydraulic reliability modelling by the links A1 and A2. The difficulty will be consequently to assign to the hydraulic links A1 and A2 the right failure rates, calculated from the segment A.

Conversely, if a Hydraulic Criticality index has been calculated for each pipe A1, A2 and A3, it will be difficult to assign a common HCI to the segment A.

Consequently it is advised to do all one can do, to have the same link and segment. This is the case in Lausanne where each segment corresponds to a hydraulic link : this is a pipe, with the same characteristics, linking two nodes (consumption, crossing of two pipes or tank).

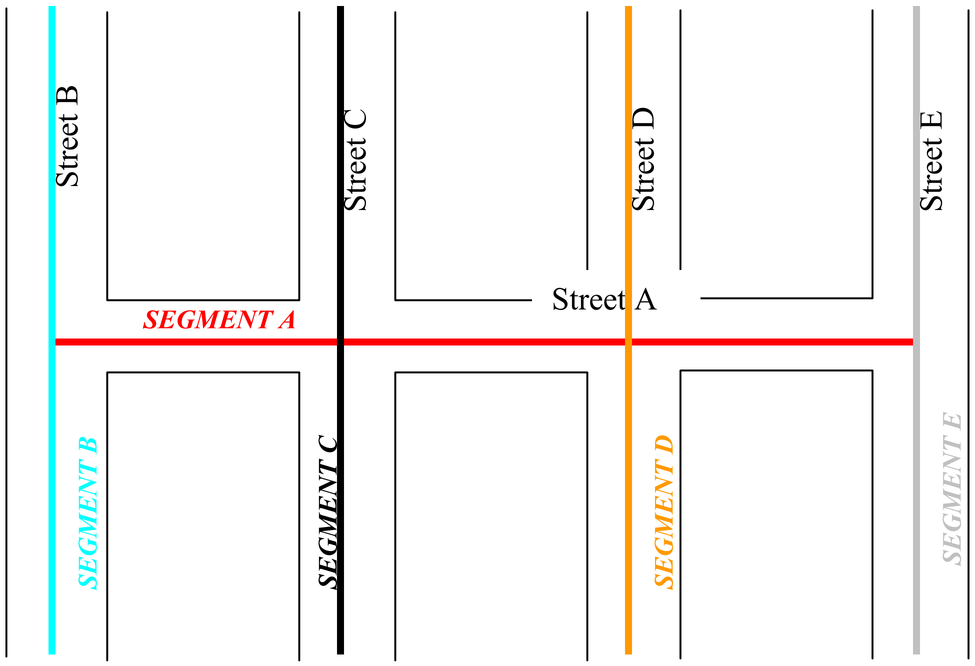

Figure 7: Definition of the segments for FAIL tools

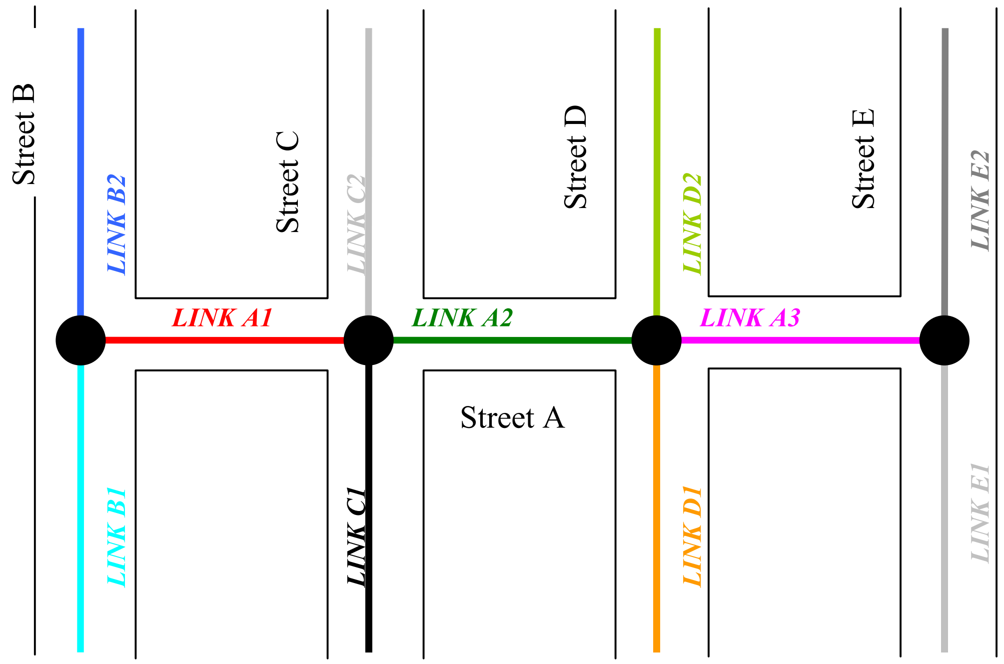

Figure 8: Definition of the hydraulic links for REL tools

3.3 Choosing which REL tool to use

The three REL tools are:
- Aquarel (SINTEF),
- Failnet-Reliab (Cemagref),
- Relnet (Brno University).

They differ by several elements: the hydraulic model used and the way to calculate the Hydraulic Criticality Index.

Aquarel uses the EPANET hydraulic model, that is a classical model, but can include a 24 hours model: the consumption is fixed and equal to the demand. Finally the Hydraulic Criticality Index varies between 0 and 1. A value equal to one means that the pipe is hydraulically the most important.

Failnet-Reliab uses a specific hydraulic model, calculating the consumption according to the head at the node. Two Hydraulic Reliability Indices are proposed. These are first the yearly non-supplied volume caused by failure (in m^3/year), and secondly the same value, divided by the total yearly water volume (varying between 0 and 1).

Relnet uses also the EPANET hydraulic model. The Hydraulic Criticality Index calculated is the impact on the water pressure of the failure of the pipe, without considering the failure rate. This is a value varying between 0 and 1. A "1" value corresponds to a total impact on all the nodes following the pipe failure.

The characteristics of each tool are summarized in Table 4.

Table 4: REL tools characteristics

Feature	Aquarel	Failnet-Reliab	Relnet
Hydraulic model	Classical model (EPANET) on 24h, considering tank water levels	Head dependent demand model (based on "Porteau" Model)	Classical model (EPANET)
Equipment integration	Yes	In progress	Yes
Failure rate integration	Yes	Yes	No
Indices	One index (0-1)	2 indices (0-1 and non-supplied water volume)	One index (0-1)

One major interest of these tools is to define the hydraulic importance of each link. This interest concerns "branch" networks, where this importance seems obvious as well as for a "looped" networks. This interest is higher when the failure rate can be included in the computation.

Figure 9 shows that even for a "branch" network, the REL tools can bring useful information. The first figure classifies the pipe according to the diameter, the second one according to the HCI (without considering the failure rate) and the third one considering the failure rate.

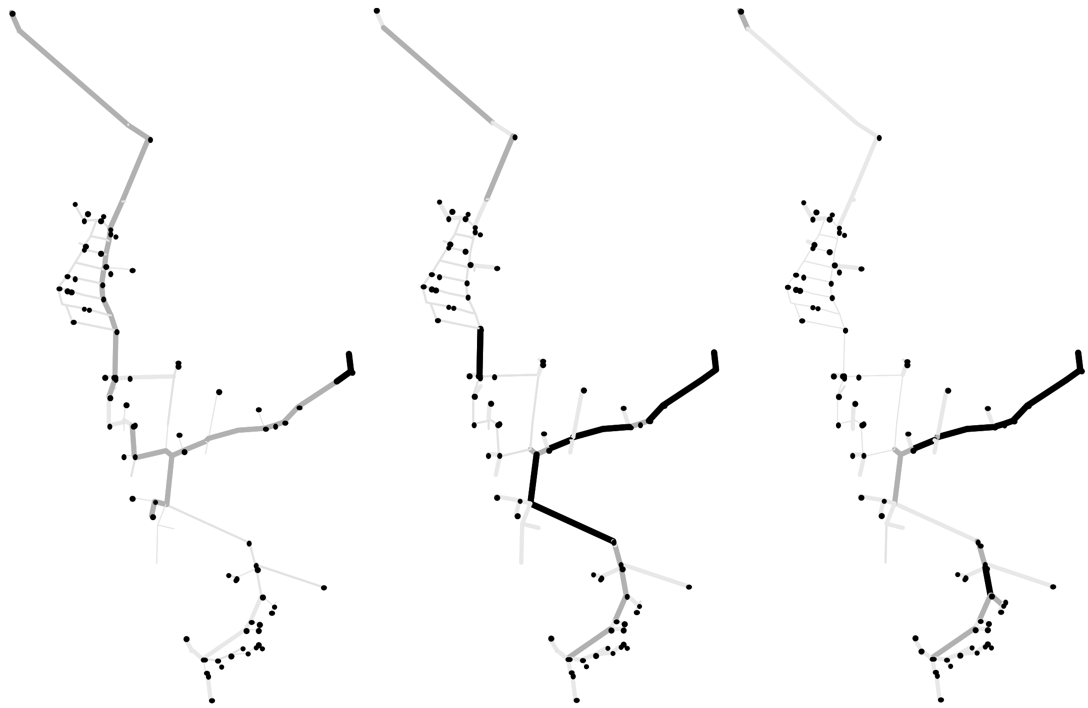

Figure 9: Comparison of results of REL tools (on the left : the thickness of the line represents the diameter, middle : HCI-Failnet-Reliab, without considering Predicted Failure Rate), right : HCI-Failnet-Reliab, considering Predicted Failure Rate)

The choice of the REL tools will depend on several aspects:

- **the existing model** : if a hydraulic model exists, it will be advisable to use Aquarel and Relnet if EPANET was used and to use Failnet-Reliab if Porteau was used. In other cases, no advice is proposed as the two file formats are Text-files and can be easily created,
- **the knowledge of pipe failure rate or predicted pipe failure rate** (for instance from PHM or Poisson): in this case it will be advised to use Aquarel and Failnet-Reliab that can include these values in HCI computation. If pipe failure rate is not known, category or general failure rate can be used,
- **the possibility of calculation on 24 hours (Aquarel),**
- **calculation time:**

Calculation time is different according to the tools. (Cf. Table 5) Relnet and Aquarel based on Epanet, are really more rapid. Failnet is slow. This is due to:

- the calculation model (head dependent model), which is a little more complicated than a classical model,
- the computer program, which has not been optimised. Several improvements are possible. The program has indeed been developed in "Matlab" language and automatically translated in C++ language.

Table 5: CPU Time for REL tools according to number of links (Pentium 4, 2.6 Ghz, 512 Mb RAM)

	Relnet	Aquarel	Failnet-Reliab
200 links	14 s	5 s	3 min
400 links	16 s	13 s	10 min
800 links	42 s	39 s	27 min

- **The number of hydraulically independent networks in the service:** it is indeed often the case. For instance in Lausanne there are 20 independent networks with different sizes. So a pipe that will have an Aquarel value equal to 1 will really have less importance than a pipe with a "1" value in a bigger network. It is then necessary to balance these HCI according to the size of the network or the water consumed in each network. The same issue occurs for RelNet. For Failnet-Reliab, the HCI is also proposed in term of non-supplied volume, which allows direct comparison with pipes from different networks.

References

EISENBEIS, P., LAFFRÉCHINE, K., LE GAUFFRE, P., LE GAT, Y., ROSTUM, J., TUHOVCAK, L., VALKOVIC, P. (2003) *CARE-W: WP2 – Description and validation of Technical tools D4 – Report on the tests and validation of technical tools.* CARE-W (Computer Aided Rehabilitation of Water networks), EU project under the 5th Framework Program, contract n°EVK1-CT-2000-00053. Cestas (F): Cemagref, October 2003, 54 p. + appendices (electronic document)

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Appendices

- **PHM Help File**
- **Poisson Help File**
- **Failnet-Reliab Help File**
- **Relnet Help File**

Care-W PHM Help File

DESCRIPTION OF CARE-W_PHM

Care-W_PHM aims to forecast individual pipe failure rate, which is one major technical indicator for defining Annual Rehabilitation Program and prioritise pipes to be rehabilitated. This indicator is useful to assess the different criteria of Care-W_ARP. Care-W_PHM analyses also the significance of vairables, which could influence pipe failure occurrences.

Method

Care-W_PHM is based on the knowledge of past, observed and recorded failures. A failure is defined in this case as a break or detected leak that has necessitated repair to the pipe.

It requires the existence of a database, sufficiently accurate, characterising network pipe links and listing failures and their occurrence date. CARE-W_PHM uses data from previous failures to develop failure forecast models, based on specific methods used in epidemiology called survival analysis. These methods analyse the time between two failures and assess the influence of different risk factors specific to the pipe or to its environment. They lead to the production of failure models, based on the Weibull model and described by the survival and hazard functions. After defining significant variables, predicted failure numbers and rates at 5 or 10-year horizons may be computed for each pipe.

The use of Care-W_PHM

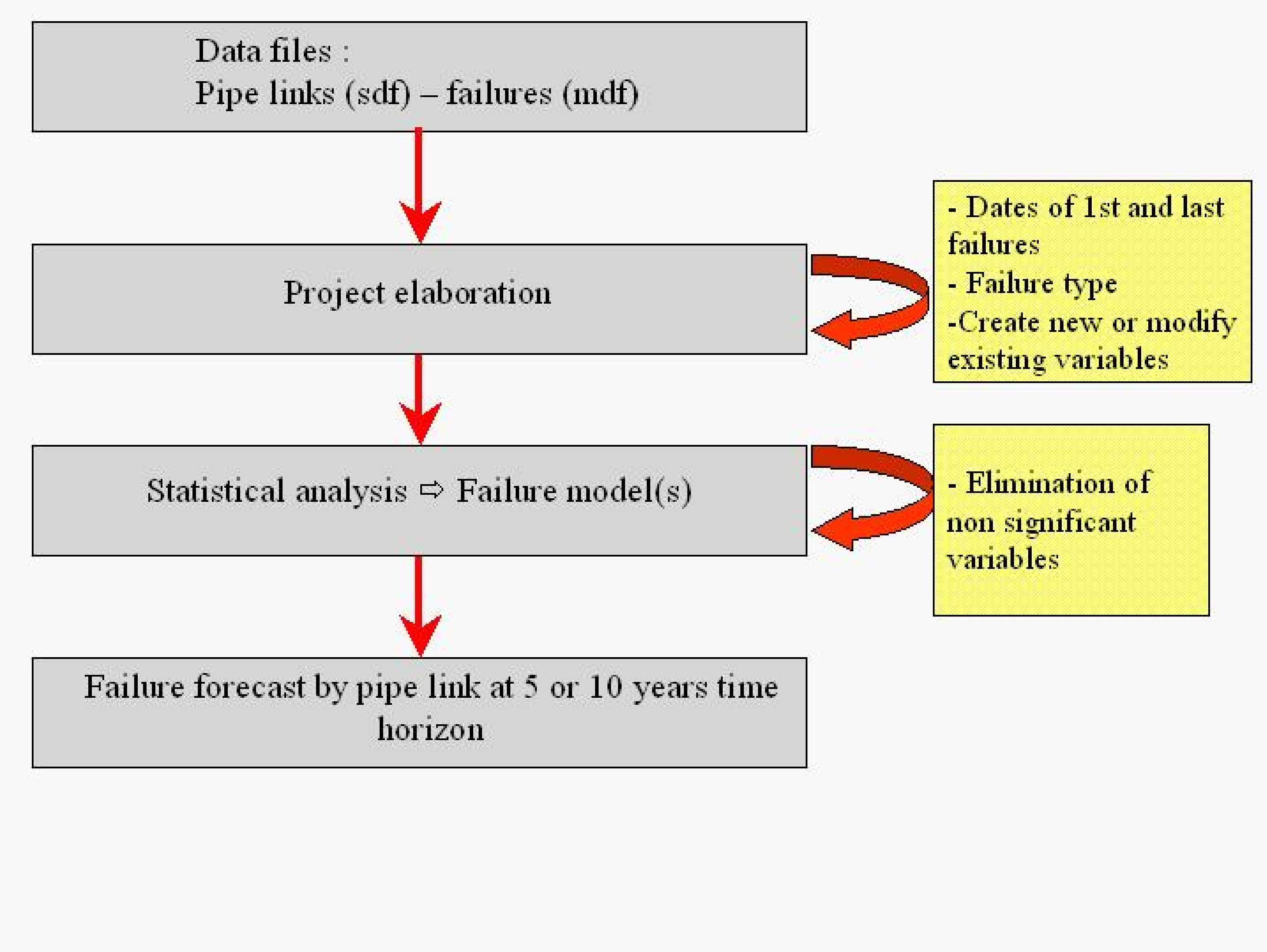
Data for these tools consists of the description of pipes ("sdf" files) and the description of their failures ("mdf" files). Pipes are defined according to the following characteristics:

- of the pipes themselves: location (street name, locality), diameter, material, installation date, internal and external protection,

- of their environment: soil (corrosivity, movement risk), traffic in the street, location in the street (under road or pavement), water quality, and so on.

In terms of pipe attributes, there are only three mandatory parameters for the software packages to function satisfactorily, viz. diameter, length, and installation date. These data must be specified for all pipes included in an analysis. If any of these are unknown, they can and should be approximated by experienced field personnel. With respect to failure data, the minimum information required is the spatial and temporal identification of each failure, i.e. the relevant pipe identifier and the date of occurrence of the event. Other data can also be useful: failure type (leak, burst,…), failure cause, repair type. It is important, however, that the data are reliable. Studies performed in CARE-W (5) have shown that it is preferable to use reliable and recent failure records (say, for the last 5 years) than older failure records, which may have been collected in an inconsistent way and/or may be less reliable.

CARE-W_PHM approach is presented in Figure below.

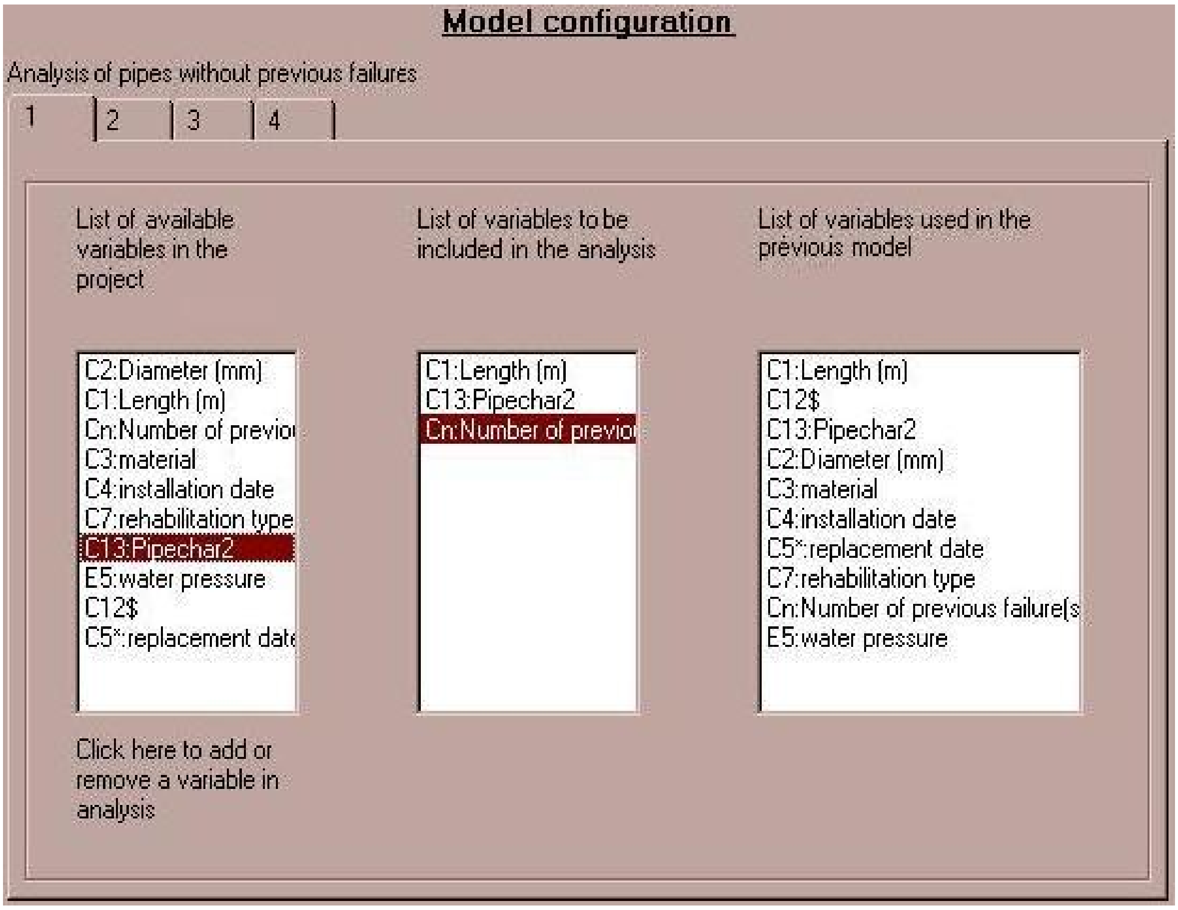


Utilisation steps of CARE-W_PHM

The first step allows the creation of a file useable for statistical analysis, selecting specific records using failure types ("burst" or "failure").

The second step (optional) is to modify or create new variables based on existing parameters to refine the model and improve the insight gained from the results. This is naturally part of an iterative process. Only by running the model and interpreting the outputs can the user refine it in an educated way.

The statistical analysis step leads to the creation of failure forecast models. These models are differentiated according to the number of previous failures which have occurred on the pipes (a fundamental principal of proportional hazard modelling). During the analysis significant variables are defined with a statistical test on a non-significance hypothesis. Figure 2 shows the analysis configuration window of Care-W_PHM. The left hand side shows the full list of variables available for inclusion in the failure model from the data provided, and indicates the current list of variables included by the user for failure model 1 (which include age, water pressure and the derived variables log (length) and log (diameter)). The right hand side of this window gives advice to the user on improving the statistical significance of the resultant failure model.



CARE-W_PHM analysis of variables

Once the models are statistically significant, failures rates and numbers may be forecast for different time horizons: 5 or 10 years (e.g. Table 2). These periods have been chosen because they can represent the evolution of failure occurrences in the short and medium term.

Comments on Care-W_PHM

The data

With respect to failure forecast models, several scenarios may occur. If the water service provider already has a database with pipe attribute information including failure data it is only a matter of adapting it to match the proposed format, which has been designed such that it is easy to use .

It is however useful to consider the following aspects:

- some data attributes relating to the pipes are indispensable, namely diameter and material;

- installation date is an essential parameter for burst assessment. Indeed, besides natural ageing, previous studies have shown that pipes laid in some periods, such as during the post-war period 1945-1950, were more likely to fail. This is also the case of the first ductile iron pipes;

- some environmental factors also have an influence on failure occurrences. This is the case for soil type, road traffic type or location of the pipe in the street (under pavement, - under road etc.). The use of Geographical Information Systems (GIS) can facilitate the consideration of this information.

- other parameters specific to water utilities can also be considered, particularly where correlations between these factors and failure data have been observed.

- with respect to failures records, the longer the history of data, the better the analysis of any trend in failures should be. However previous studies show that, in some cases, recent data are preferable to longer historical records. Recent data may be more consistently recorded and reliably collected. There may have been a change in reporting procedures and practices or losses from data transfer to newer replacement data management systems which means that direct comparisons with older datasets are impossible.

If a service is to set up network maintenance databases in a systematic way, it is advisable to use record forms which can be used to describe accurately the failure date, type and cause, and provide information on pipes and their environment during the repair (e.g. material, diameter, soil type, lining condition, bedding materials).

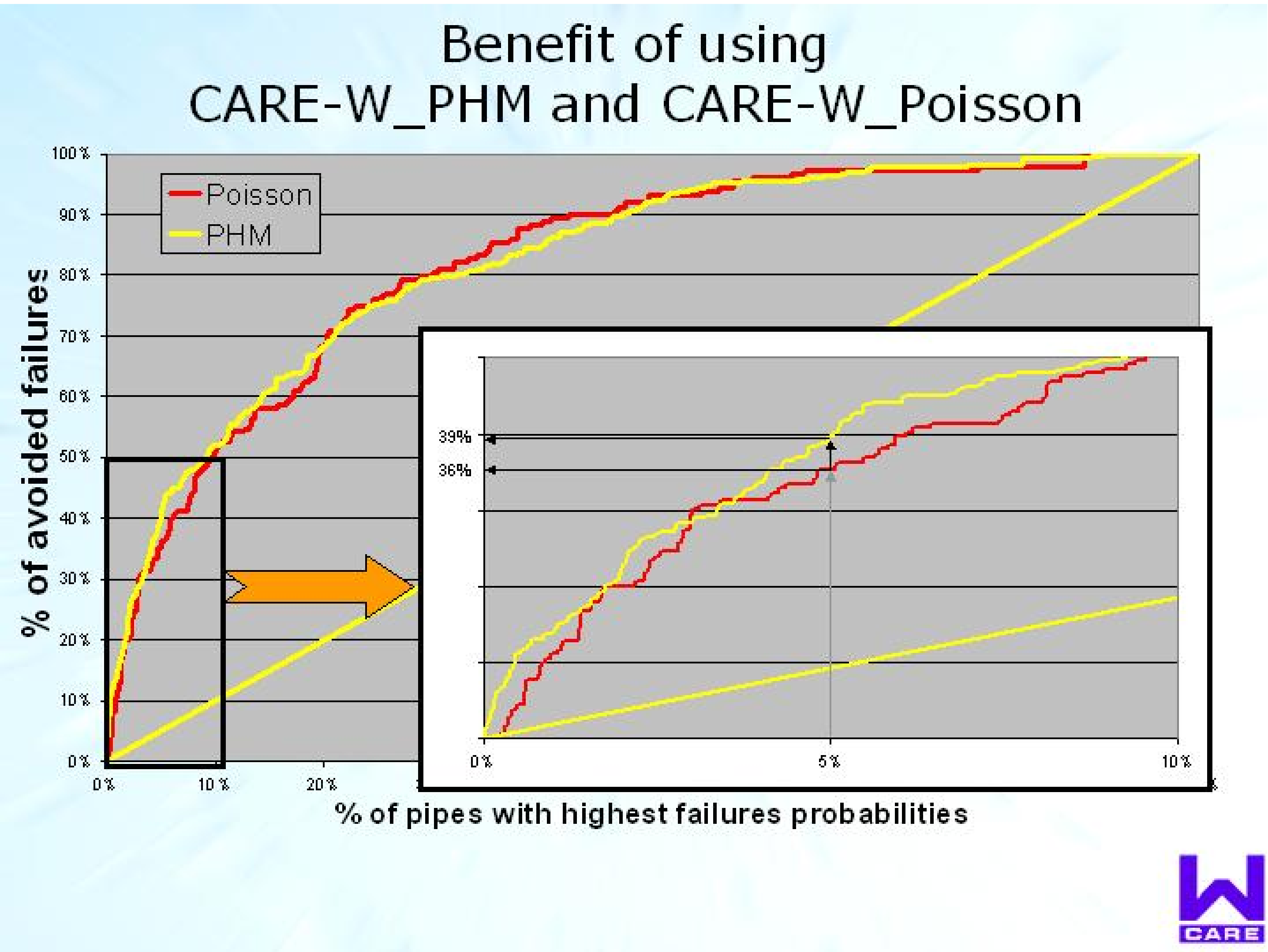
These data may then be used by CARE-W_PHM. Tests performed in the CARE-W project have shown in a short space of time that, depending on water utility size, a minimum of 3 to 5 years of records should allow a reasonable or good failure forecast. This was deduced from a comparison of forecasted and observed failures.

Benefit of CARE-W_PHM

During the CARE-W project, the different models described above have been tested in a number of European utilities (5).

For failure forecast models, the tests consisted of assessing the benefit of the models. The objective was to compare forecast and observed failures. Consequently it was possible to define the number of failures avoided if a defined percentage of pipes had been rehabilitated.

Figure below shows an example of this Benefit curve with CARE-W_PHM and CARE-W_Poisson on the Trondheim network. If the top 5% of pipes (classified by predicted failure rate, highest first) had been rehabilitated, this should have resulted in a decrease in observed failures of between 36 and 39%, together with a reduction in costs linked to these failures. Note, too, that the two FAIL models give similar results.



Some references on Care-W_PHM

EISENBEIS, P., LAFFRECHINE, K., LE GAT, Y., LE GAUFFRE, P., ROSTUM, J., TUHOVCAK, L. ,CARE-W: WP2 - Test and validation of technical tools D4 - Report on models description. CARE-W, EU project under the 5th Framework Programme, contract n°EVK1-CT-2000-00053. Cestas (F): Cemagref, September 2003.

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LE GAT, Y., EISENBEIS, P., Using maintenance records to forecast failures in water networks, Urban Water, 2000, 2, (3), 173

LOAD OR CREATE A PROJECT

- Menu--->Files\Create a new project

Two data input files are used with PHM: an *sdf* file describing the pipes and an *mdf* file describing the failures. For computations, an additional file is created: the *survive* file describes "individuals" (an individual is one pipe characterised by its number of previous failures and a censored variable) and the time intervals between failures.

First select the input files you want to use. Check your mdf file, it must have less than ten columns to work with this application (usually mdf file contains no more than five columns, M1, M2, M3, M4, M5).

Then click on the first "validate" button. The application will then analyse the mdf file. This analysis will calculate the first and last dates of failure observation and show if the file contains break or failure type data. The observation period can be changed (using the format: DD/MM/YYYY) and, if applicable, analysis by failure type can be selected (e.g. just use records categorised as breaks, as failures or all records). To end the new project creation, click on the next "validate" button. A new file named "temporaire_statistique.txt" will be created. This file can be saved when it has been created.

- Menu--->Files\Load an existing project

If required, a previously created project can be loaded. It must be a project created by PHM. A new file "temporaire_statistique.txt" will be created, this file is a copy of the original file just loaded. PHM always works with a copy of the file and not the original, in case modifications are made.

- Menu--->Files\Save the current project

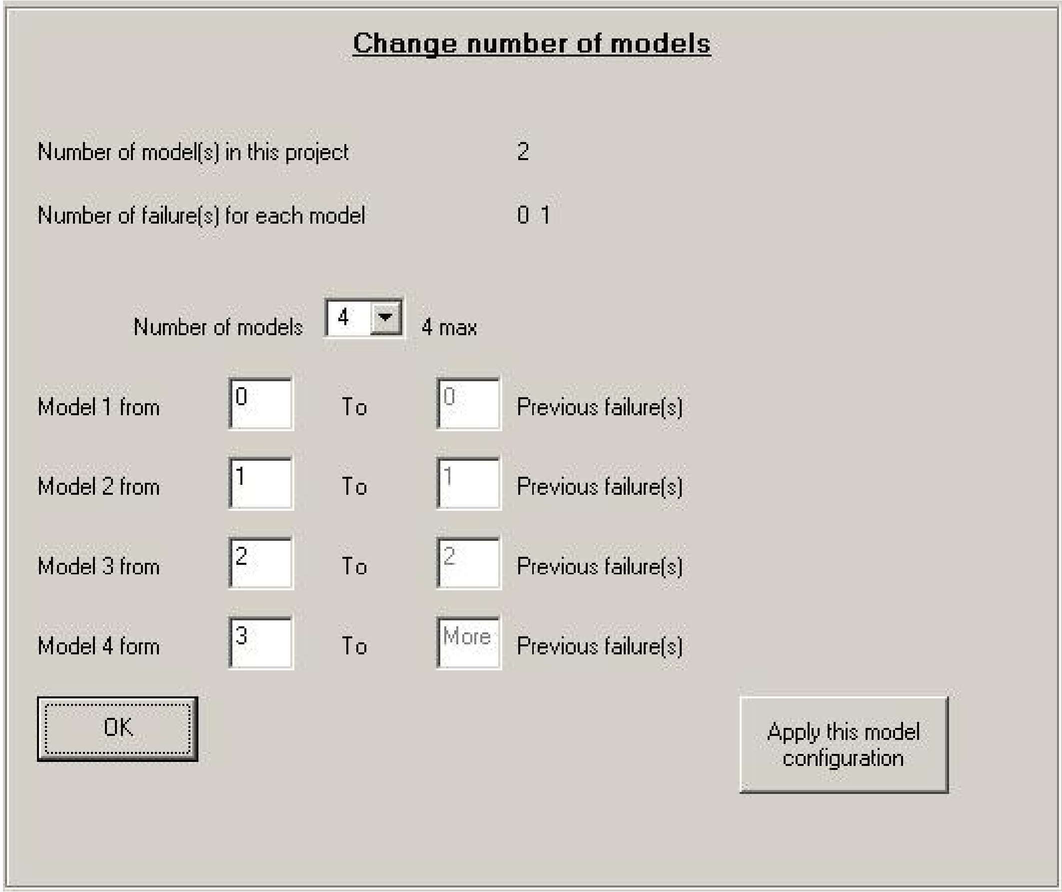
As soon as you create a new project or load an existing project this button is enabled. You can use it at any stage and by supplying a filename, PHM will make a copy of the file "temporaire_statiqtique.txt" with this name. PHM always provides a default name (generally the name present in the mdf file).

CHANGE NUMBER OF MODELS

Menu--->Project\Change number of models

The number of statistical models to consider in the analysis can be changed, as a function of the number of breaks in any individual pipe. The first two lines show the number of models in the current project and number of failures associated with each model.

By default two models are considered in the analysis:
- model 1: for individuals without previous failures.
- model 2: for individuals with one or more previous failures.



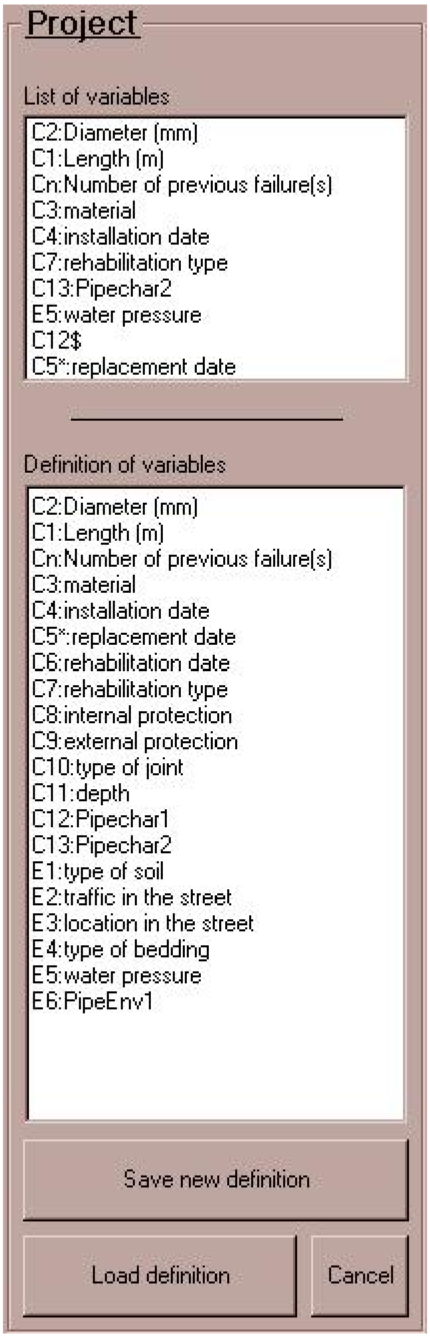
To change the number, choose the new number of models and the new minimum number of failures for each model. A project can have a minimum of one and maximum of four models.

After defining the required configuration, click the "validate" failures button. PHM will calculate the number of previous failures for each model. Then click the apply button, to change the "temporaire_statistique.txt" file. The model configuration dialog will then open automatically.

VARIABLE DEFINITION

This part of the program allows changes to the definition of variables to be made. There are two windows, one with the name of all the variables present in the current project and the other with all the definitions of known variables, relevant to the analysis. If a variable present in the current project, has a defintion in the definition file, PHM uses this definition as the name of this variable.

The definition of variables can be changed and saved. This is performed by adding a new definition or changing an existing one. Note that the file "variable_name.ini" present in the directory, ini, is the default definition file. For PHM to start with a different definition file, simply replace this file with a new definition file.



Clicking on the "cancel" button will load the default definition file ("variable_name.ini").

ADD A VARIABLE

This part of the program allows new or modified variables to be added. A predetermined or user-defined variable can be added. PHM can only work with numeric modalities, therefore new variables should not contain alphanumeric or empty modalities.

All new variables are added to the list named "added variable".

A) Predetermined variable:

Just select one of the four predetermined variables in the list:

1. LogOfLength
2. LogOfDiam
3. LogNbDef
4. Age

This variable will be added to the "added variable" list. PHM uses some existing variables to make the new ones: Length, diameter, number of previous failures and installation date, are always at the same place in the project file. They should not be moved or removed, otherwise the function "add predetermined variable" will not work correctly.

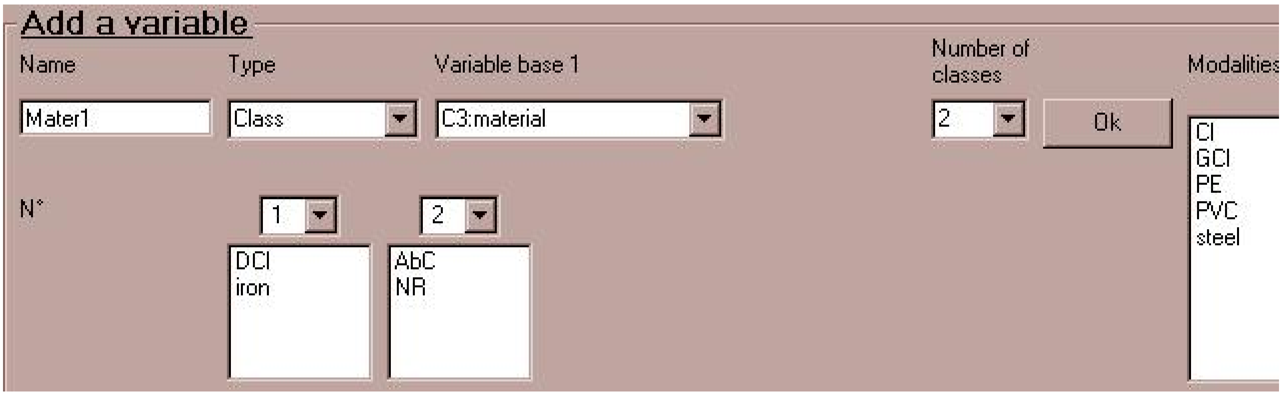
B) User-defined variable:

Firstly, choose the name and the type of the new variable. The name must be alphanumeric (ten characters maximum). If this name is already used by a variable of the project, PHM will automatically change the name (if for example, "Diam" is already used, it will be changed to "Diam.1" and if "Diam.1" is already used, "Diam.2" etc.).

For the type, there are three choices:

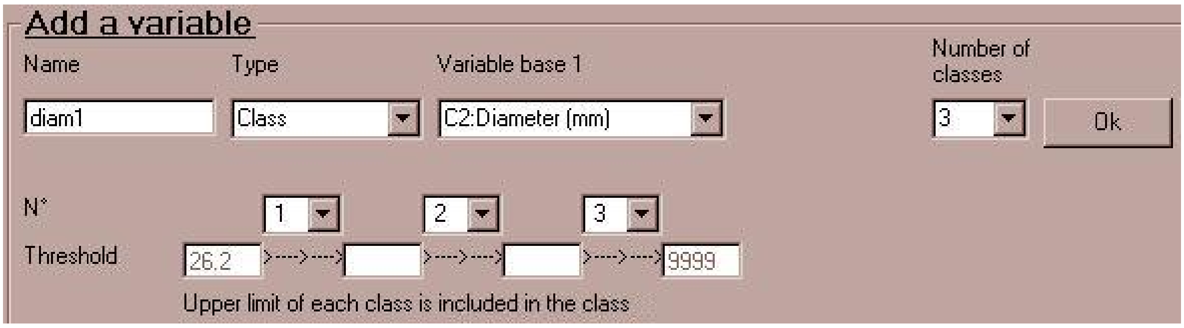
1. Class - For this type, classes based on the differents modalities of an existing variable can be created. Choose the variable to use ("variable base 1") and the number of classes. Phm will check the variable you selected:

   - --->For a qualitative variable:
     PHM asks whether or not to group modalities of the chosen variable. Selecting "yes", enables specific user-chosen classification of the modalities. Selecting "no" facilitates grouping of variables as per those that are "continuous".

     To group some modalities, just drag the appropriate ones from the list of modalities on the right and drop them in the class required. All the modalities of the variable must be used and empty classes are not allowed.

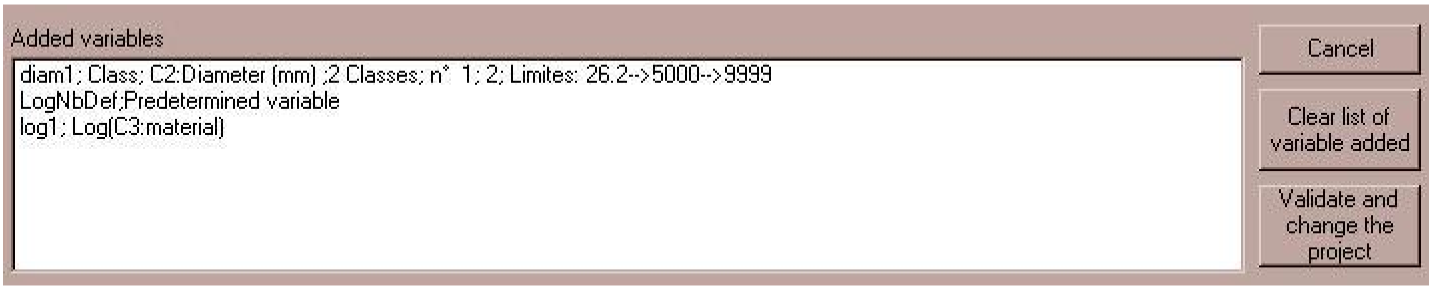
   - --->For a "continuous" variable:
     PHM will calculate automatically upper and lower limits for the variable, and intermediate thresholds can be defined to determine the classes.

2. Log - For this type, the logarithms of all the modalities of an existing variable are calculated. Just choose the variable to use ("variable base 1") and click on "OK", PHM will calculate automatically the logarithm of each modality. The new variable will be added to the list "added variable".

3. Prod - This type allows the multiplication of the modalities of two existing variables. Just choose the variables to use ("variable base 1" and "variable base 2") and click on "OK", PHM will automatically calculate the product. The new variable will be added in the list "added variable".

After adding the variable(s) click on the button "validate and change the project"



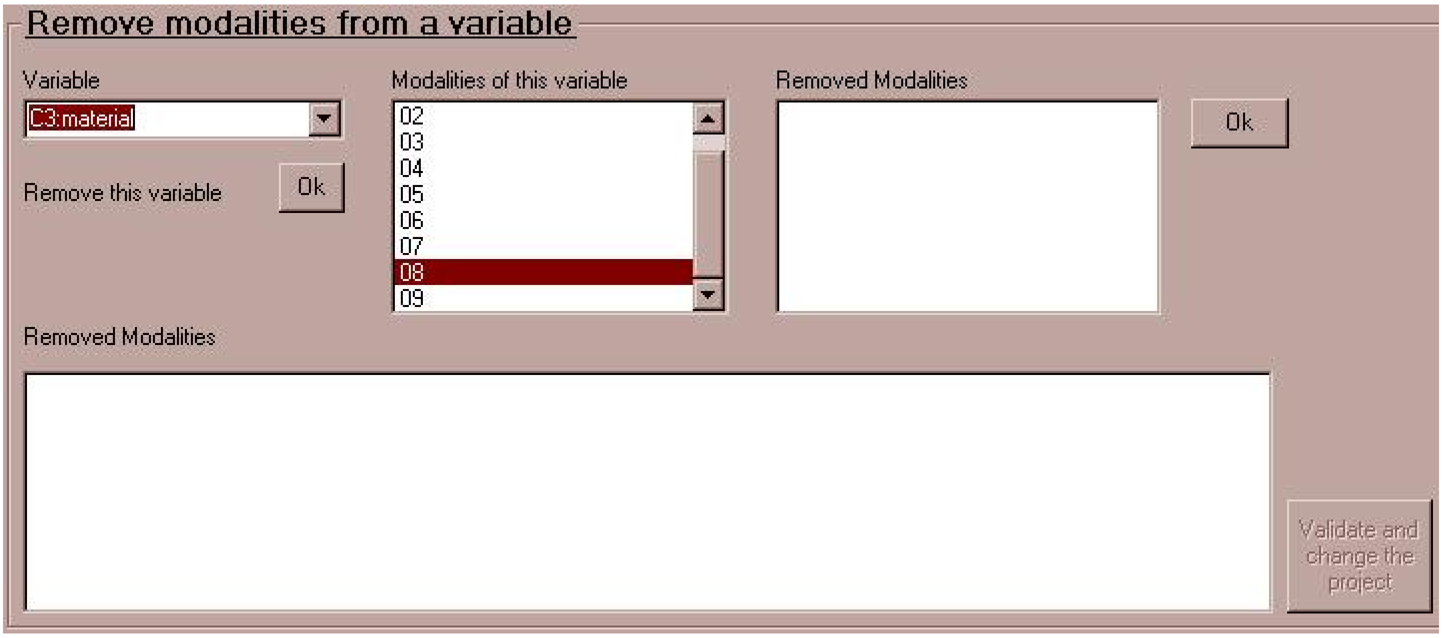
The button "clear" is used to clear the upper part of this windows (name, type and var base 1). Clicking on the button "clear list of variable added" will remove all the variables you have just added. Clicking on the button "validate and change the project" will add the new variables to the project and refresh the windows to show that they have been integrated into the project.

After validation PHM will add "------>OK" to the left of the new variable just added (in the added variable list). To remove a variable with ("----->OK") the "remove variable" option must be used.

<u>Important notice</u>: PHM can't work with more than 20 variables, but variables can be removed to make room for new ones.

REMOVE VARIABLE OR MODALITIES

This part of the program allows some modalities of a variable or the entire variable to be removed.



Select a variable and PHM will display all its modalities. Then, just click on the modalities to be removed from this variable. Clicking again on the same modalities will reinstate them. The list named "Removed Modalities" contains the list of the modalities to remove, click on the "OK" button to validate your choice. The list "Removed Modalities" will display the names of the variables and the list of the modalities to be removed. Click on "Clear the list of removed modalities" to cancel. Click on the button "validate and change the project" to apply the changes to the project. The windows will refresh and all discarded modalities will be removed from the project.

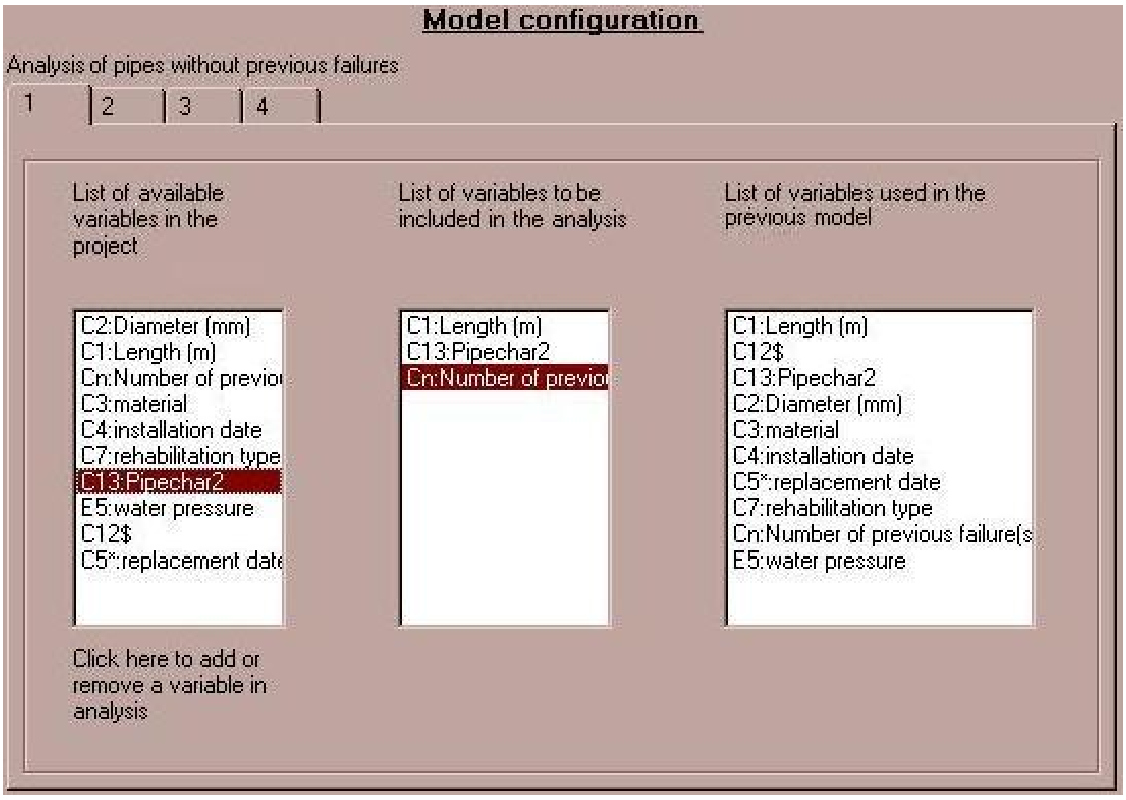
It is also possible to remove an entire variable. Just select the variable and click on the "OK" button beside the "remove this variable" text. A warning message is displayed and asks for confirmation. The windows will refresh and the variable will be removed from the project.

Note: Make sure not to remove a variable used for the creation of a new variable before it has been validated.

ADD OR REMOVE VARIABLES FROM ANALYSIS

Here, the model configurations can be changed.

A maximum of four models are available. To select a particular model, just click on the tab of the model number required. PHM will display the number of previous failures for this model, if it is available.



For each model there are three lists, a "list of variables available in the project", a "list of variables to include in analysis" and a "list of variables used in the previous model". To configure each model just click on the variables required in the "list of variables available in the project" and they will be added to the "list of variables to include in analysis". If necessary, click again to remove the variable from the model. The last list displays the variables used in the previous analysis.

The configuration is validated by clicking on the button "Run calculations". This should only be done when all the models have been configured.

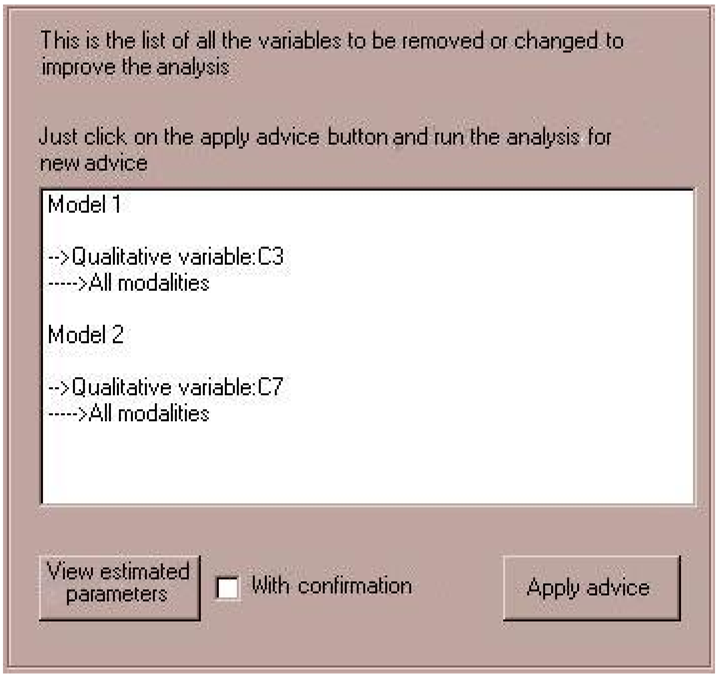
ADVICE

In this part of the program, advice is given, regarding the configuration of the project.

Before runing the detailed calculations, there is an option to receive advice, relating to the statistical significance of the variables used in each model. Check the "Using advice" box to use this facility.

PHM will calculate the estimated parameters for each model. These parameters can be viewed in the file "paresti.txt", by clicking on the button "View paresti file". PHM will check the values for each variable and each model and then, if necessary, recommend which variables should be removed or changed in order to improve the analysis.

Click on "apply advice" to let PHM automatically make the proposed modifications. Checking the "with confirmation" box will allow the application of each change to be confirmed by the user. A number of iterations may be required before a "no changes necessary" message is displayed.



In this example, two models are used. In the first, the variable C3 must be removed and in the second model the variable C7 must be removed.

Note, care should be taken to avoid using two or more variables that are closely correlated, (e.g. Log of Length and Lengh). PHM will display an error message if this occurs.

CONFIGURATION OF TIME HORIZON

Here, the forecast time horizon can be changed.

If the forecasted time horizon is set to 0, PHM will only calculate the estimated model parameters. For a complete analysis, change the value of the time horizon to between 0 and 100 years.

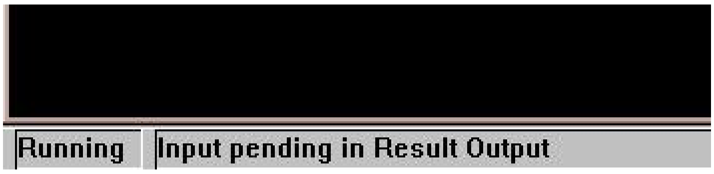
All the settings are validated by clicking on "run calculations"

RUN THE PREDICTIONS AND VIEW THE RESULTS

I) RUN PREDICTIONS

To run the predictions just click on the button "Run calculations". For advice or complete analysis just check or uncheck "using advice", the corresponding configuration or time horizon window will then be shown.

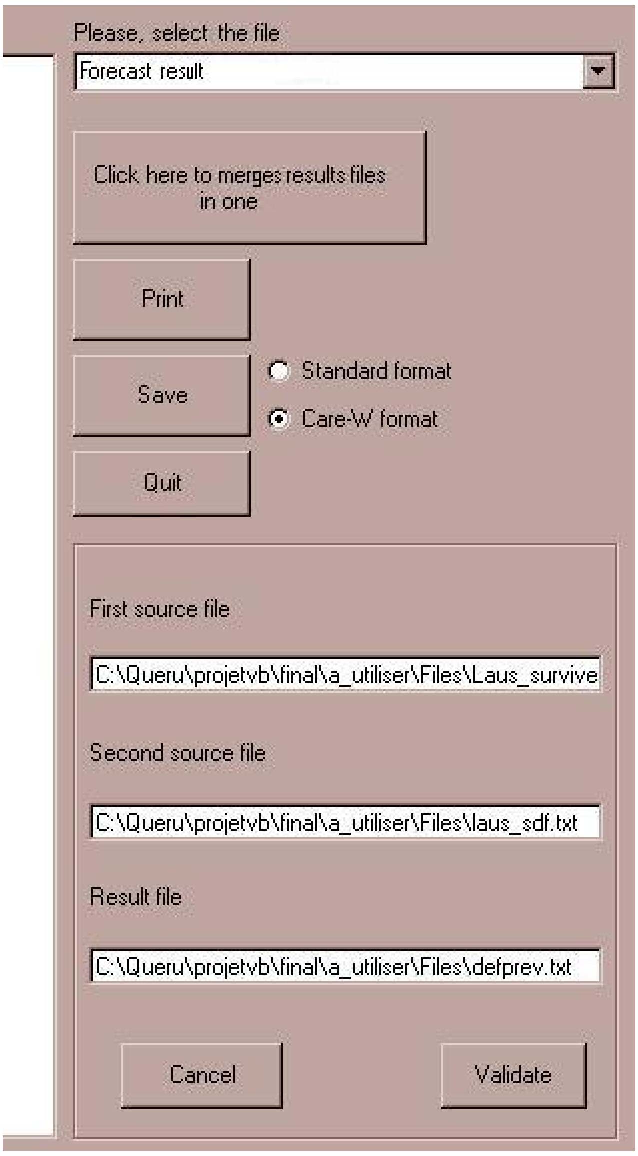
PHM will launch the calculations part of the program and a DOS Window will open. Follow any instructions given and finally click on "yes" when asked to "exit window?".



Two parameters for the calculations can be changed by modifying the file, "config.txt": the number of simulations and the estimated time step.

II) VIEW RESULTS

The "view results" part of the menu is not activated until a complete analysis has been made (with time horizon greater than 0).
Then, the three result files can be viewed and saved.



A list is displayed with the name of the three results files. Select one and it will open in the left part of the window.

The three files are:

1. Forecast result
   These are the results of the forecast, pipe by pipe, ranked from the pipe with the highest failure risk to the pipe with the lowest.
2. Estimated parameters of the models
   This provide the results concerning the influence of parameters.
3. Discarded pipes for missing values
   This provides a list of pipes discarded from the analysis because of missing or invalid values.

Any of the three files can be saved by clicking on the "save" button, after selecting the required format (standard or CARE-W):

--->Standard format is the default format.
--->Care-W format can only be used with the "Forecast result" files, and.

For both formats select the path and filename required. The new file will be opened in the left window and a new link will be available in the upper righthand list. After quitting this part of the program, the link will be removed.

It is also possible to merge two files to form a new one. Just click on the first and the second source files to give the path of these files and define the path of the combined result file.

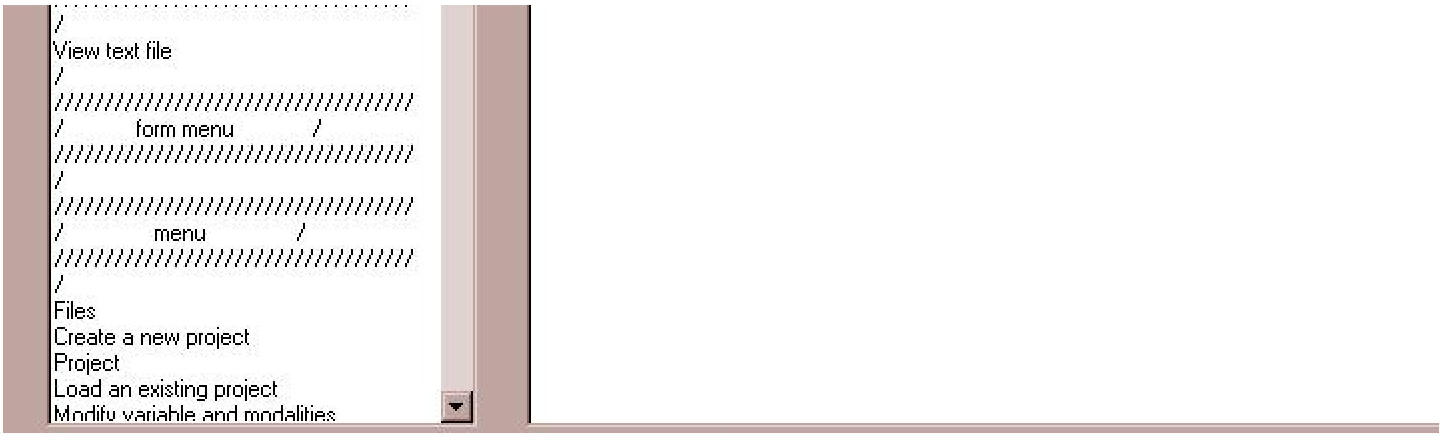
Note, it is possible to save a project at any time by clicking on: "Files/Save the current project". This will provide a default filename (generally the name of city of the input datafiles). If required a new name can be entered before clicking on the "OK" button. If you quit PHM without saving the project, the last version of the "survive file" can still be retrieved. It is stored under "Temporaire_statistique.txt" in the Temp directory. Simply rename this file to prevent it from being replaced in subsequent uses of the program.

DESCRIPTION OF TOOLS

There are two principal tools in the menu Tools.

1. Open and view a text file
   A new window displaying the chosen file will be opened. The file can be edited, printed or saved.

2. Use or make a translation file
   To use a translation file, just give the path of this file and PHM will use it.
   To make a translation file, a new window will open:



By loading and modifying a translation file, messages can be displayed in different languages. Simply replace the phrases given, with those in the language required. Lines begining with "/" are comment lines and are ignored by PHM.

DESCRIPTION OF FILES USED IN THIS APPLICATION

Several types of files are used in PHM:

I. Input files - There are two input files: an sdf file, describing the pipes and an mdf file, describing the failures. These two files are not used directly for the computation. An intermediary file, called a "Survive file", is created instead. It describes individuals (one individual is one pipe characterised by a previous number of failures and a censored variable) and the time intervals between failures. Survive files can be saved by choosing "save the current survive file" in the menu "File".

II. Output files - After the computations have been made, several output files are available:
   - -->defprev.txt: contains the forecast results,
   - -->paresti.txt: contains the results of the parameter estimation,
   - -->rejet.txt: lists the pipes rejected from the analysis because of missing or non-valid data.

   The forecast result can be saved in Care-W format. The name of the output file has to follow the following standard:
   - · If the analysed events are failures, the name should be :
CITYNAMEpfr5.txt for the results of a 5 years forecast,
CITYNAMEpfr10.txt for the results of a 10 years forecast

   - · if the analysed events are bursts, the name should be :
CITYNAMEpbr5.txt for the results of a 5 years forecast,
CITYNAMEpbr10.txt for the results of a 10 years forecast

III. Temporary file- During the use of PHM, a temporary file is used. It is in the folder "temp" and is called "Temporary_survive_file.txt". All modifications made during PHM (new variables, removing modalities, model configurations) are saved in this file. This survive file can be saved during the use of the program.

IV. Initial files - There are two initial files:
variable_name.ini: provides the definition of the varibles
translate_default.ini: provides all command names and text used in PHM in a specific language (English by default)

V. Language files - These files allow the text in PHM to be displayed in different languages. Two files are available:
translate_fr.txt (French)
translate_uk.txt (English).
A new language file can be created using the menu "Translation\Make a translation file" and applied by choosing "Translation\Use a translation file".

VI. Exe files - Two sub-programs are used in PHM:
surv1.exe
Fstat.exe.

DESCRIPTION OF KNOWN PROBLEMS

-->This application use the regional parameter to identify numbers (e.g. 2,2 or 2.2); so ensure the correct format is used for the sdf, mdf or survive files. The "." as decimal parameter is advised.

-->All the files used in PHM have a fixed place (Exe\FStat.exe, Exe\Surv1.exe, Files\Config.txt, Ini\Translate_default.ini, Ini\Variable_name.ini and Help\Phm_help.chm). Please don't move these files to another directory or Phm will not work correctly.

-->The date format is different between several European country, please use this format: DD/MM/YYYY

Care-W Poisson Help File

CARE-W_POISSON tool

Tool version Number: 1.02
Help file version number: 1.0
Author: INSA Lyon (France)
Date: Decembre 2002

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DATA – STEP 1

Two types of data are used:

Pipe description data

This concern the description of the pipes existing in the network.

The data are

- pipe characteristics (Identification n°, street, diameter, length, installation year) and/or
- environmental characteristics (soil type, water quality, pressure, traffic, location, average number of service connections …)

All data, that could influence a priori failures occurrence, can be included

Maintenance data

This concerns the failures occurred on the network and their characteristics (date, type of failure, pipe concerned …)

PIPE DESCRIPTION DATA

File: **City_sdf.txt** (example), generated by the CARE-W data manager
This concerns the description of the pipes existing in the network. That data are pipe characteristics:

Code parameter	**Prototype parameters** (coming from central database)	**Description**	**Type of data** (Numeric or alphanumeric)	**Unit** (if Quantitative)
I1	ID	User reference (Pipe Id)	Alpha	
I2	Street, Road or locality	Street, Road or locality	Alpha	
I3		area (municipality or region or zone),	Alpha	
I4		Geodetic coordinates	Alpha	'
C1	Length	Segment length	Number	m
C2	Diameter (nominal)	Segment diameter	Number	mm
C3	Material	Segment material	Alpha	
C4	YearLaid	Date of installation	Date	Day (DD/MM/YYYY) *or* Month (MM/YYYY) *or* Year (YYYY)
C5	DateAbandoned, replaced	Date of replacement of the segment	Date	Year (YYYY)
C6	Date of rehabilitation	Date of rehabilitation of the segment	Date	Year (YYYY)
C7	Internal lining	Internal protection	Alpha	
C8	External lining	External protection	Alpha	
C9	Joint type	Type of joint	Alpha	
C10	Depth of installation	Depth	Number	m
E1	Type of soil	Type of soil (or soil resistance)	Alpha	mΩ
E2	Traffic in street	Traffic in the street or road	Num. Or Alpha	Number of vehicles/time or class of traffic intensity
E3	Pavement (surface type)	Location of the segment in the street (under sidewalk or pavement)	Alpha	
E4	Bedding	Type of bedding	Alpha	
E5	Average Working Pressure	Pressure in the segment (static max. or dynamic min. or max. difference between static and dynamic)	mPa	
E6	Number of service connections	Number of Service Connections	Integer	Count
E7				
E8				
	All data, that could influence a priori failures occurrence can be included			
E9				

MAINTENANCE DATA

File: **City_mdf.txt** (example), generated by the CARE-W data manager
This concerns the failures occurred on the networks and their characteristics.

Code parameter	**Prototype parameters** (coming from central database)	**Description**	**Type of data** (Numeric or alphanumeric)	**Unit** (if Quantitative)
M1	ID	User reference (Pipe Id)	Alpha	
M2	FailureDate	date of failure	Date	Day (DD/MM/YYYY) or Month (MM/YYYY) or Year (YYYY)
M3	Maintenance type	Type of failure	Alpha	
M4	CauseOf failure	Cause of the failure	Alpha	
M5	Type of Repair	Type of repair	Alpha	
M6	…			

PIPE DESCRIPTION DATA - EXAMPLE

```
Example1;;;;;;;;;;;;;;;
I1;C1;C2;C3;C4;C5;C7;C8;C9;C10;E4;E7;E8;E9;F1;F2
204892;5;150;DI;1984;;2;7;4;0;0;0;0;0;0;1
215406;6;100;DI;1986;;2;1;4;0;0;0;0;0;0;1
209761;32;100;DI;1988;;2;7;4;0;0;0;0;0;0;1
223182;8;150;DI;1998;;2;7;4;0;0;0;0;0;0;1
222515;177;150;CI;1939;;0;1;4;3;2;0;1;0;0;1
201450;96;150;CI;1931;;1;1;4;0;0;0;0;0;0;1
202707;6;150;DI;1994;;2;7;4;0;0;0;0;0;0;1
200704;45;100;CI;1901;;0;0;4;0;0;0;0;0;0;1
212899;39;80;CI;1959;;1;0;4;0;0;0;0;0;0;1
203284;63;80;DI;1988;;2;7;4;0;0;0;0;0;0;1
203319;13;150;DI;1979;;2;7;4;0;0;0;0;0;0;1
211280;82;80;CI;1936;;0;0;4;0;0;0;0;0;0;1
212221;63;100;CI;1933;;0;0;4;0;0;0;0;0;0;1
……
```

MAINTENANCE DATA - EXAMPLE

```
Example1;;;
M1;M2;M3;M6
200017;28/09/1993;Long;pipe
200085;16/08/1999;Long;pipe
200142;22/04/1988;Long;pipe
200173;04/05/1986;Long;pipe
200175;10/07/1985;Long;pipe
200199;27/08/2001;Long;pipe
200234;08/06/1988;Long;pipe
200243;11/05/1994;Long;pipe
200243;24/03/1995;Long;pipe
200245;03/03/1999;Long;pipe
200538;10/08/1990;Long;pipe
200580;19/07/1999;Long;pipe
200674;25/09/1985;Long;pipe
200674;18/08/1994;Long;pipe
200674;02/01/1998;Long;pipe
200791;24/04/1996;Long;pipe
200793;18/09/1996;Long;pipe
200849;28/11/1990;Long;pipe
……
```

DEFINE CATERGORIES – STEP 2 & 2'

Step 2-1

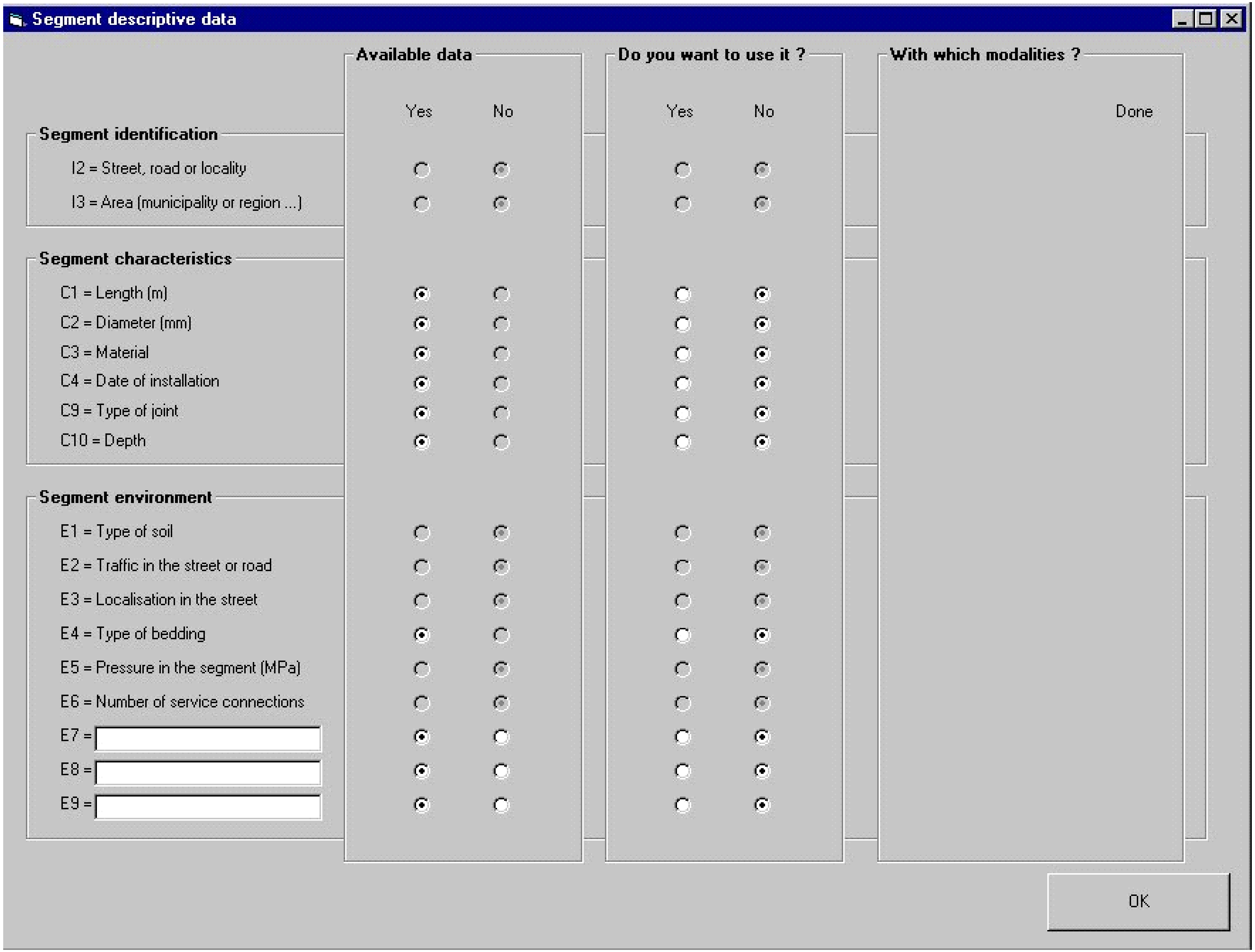
The tool proposes to the user the set of variable available in the data manager (sdf file).
The user choose variables which are supposed to correspond to explanatory factors for failure (burst or leaks) rates.

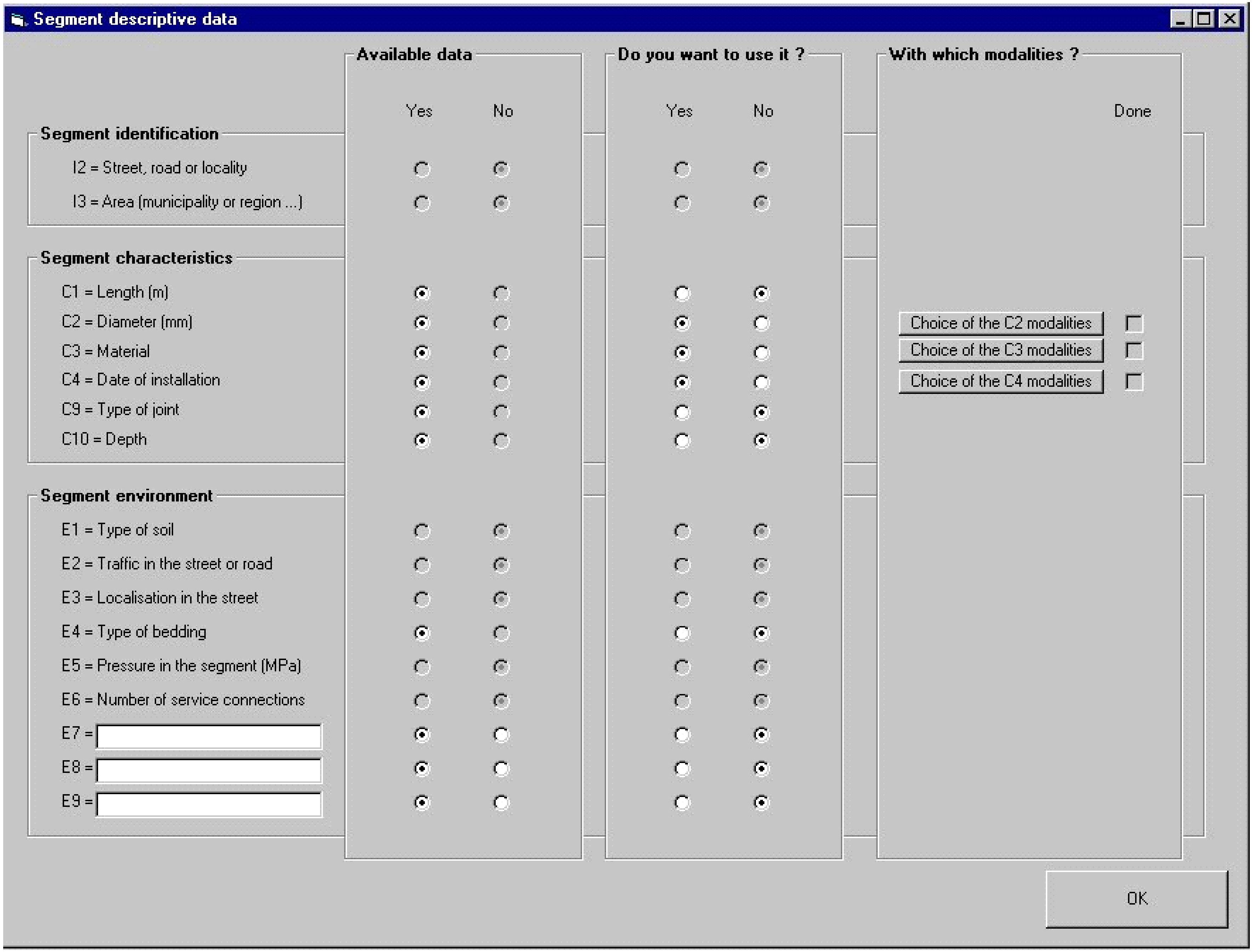
Step 2-2

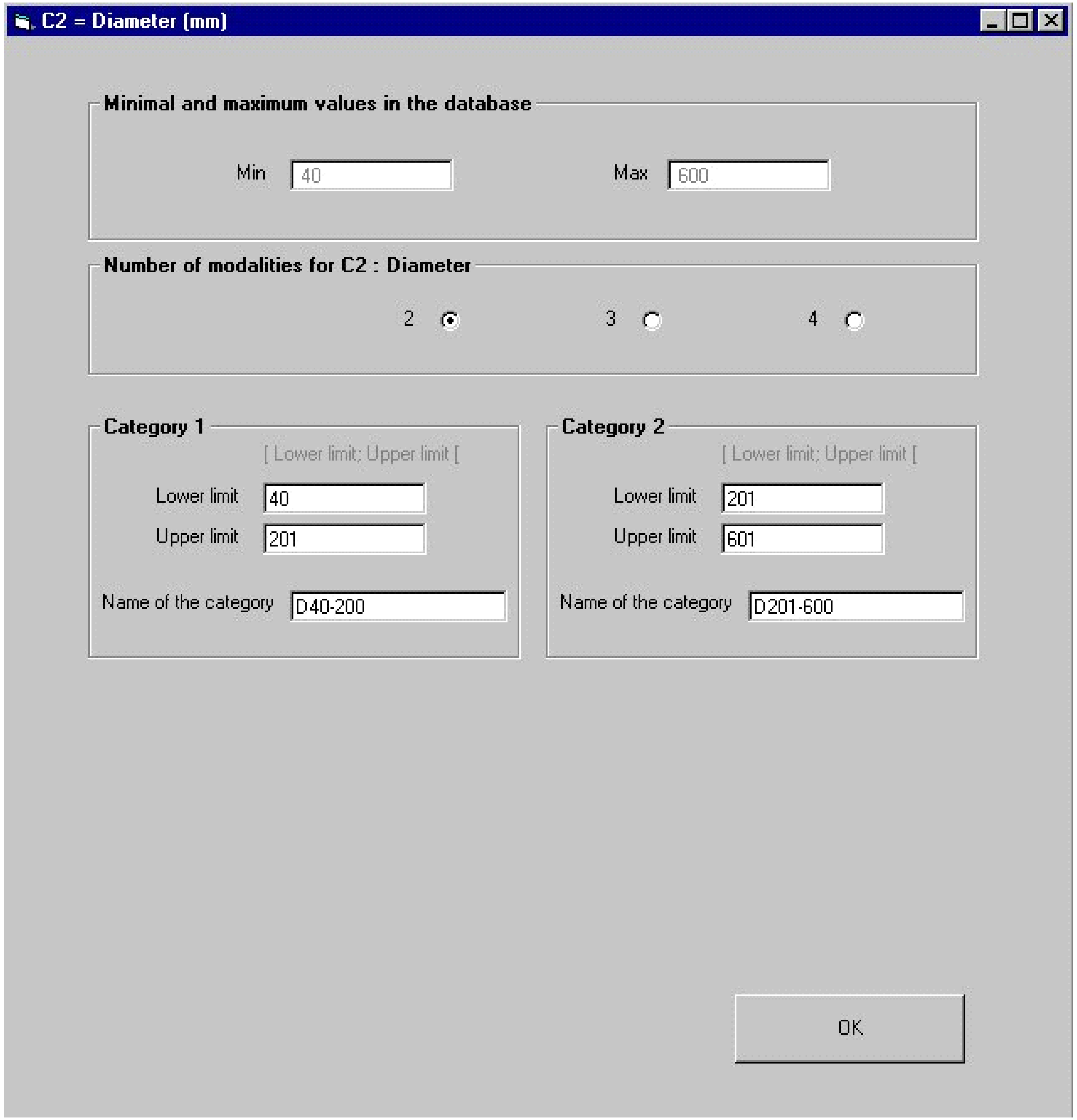
For each explanatory factor (variable) associated modalities are chosen.
Then categories can be visualized

Step 2'

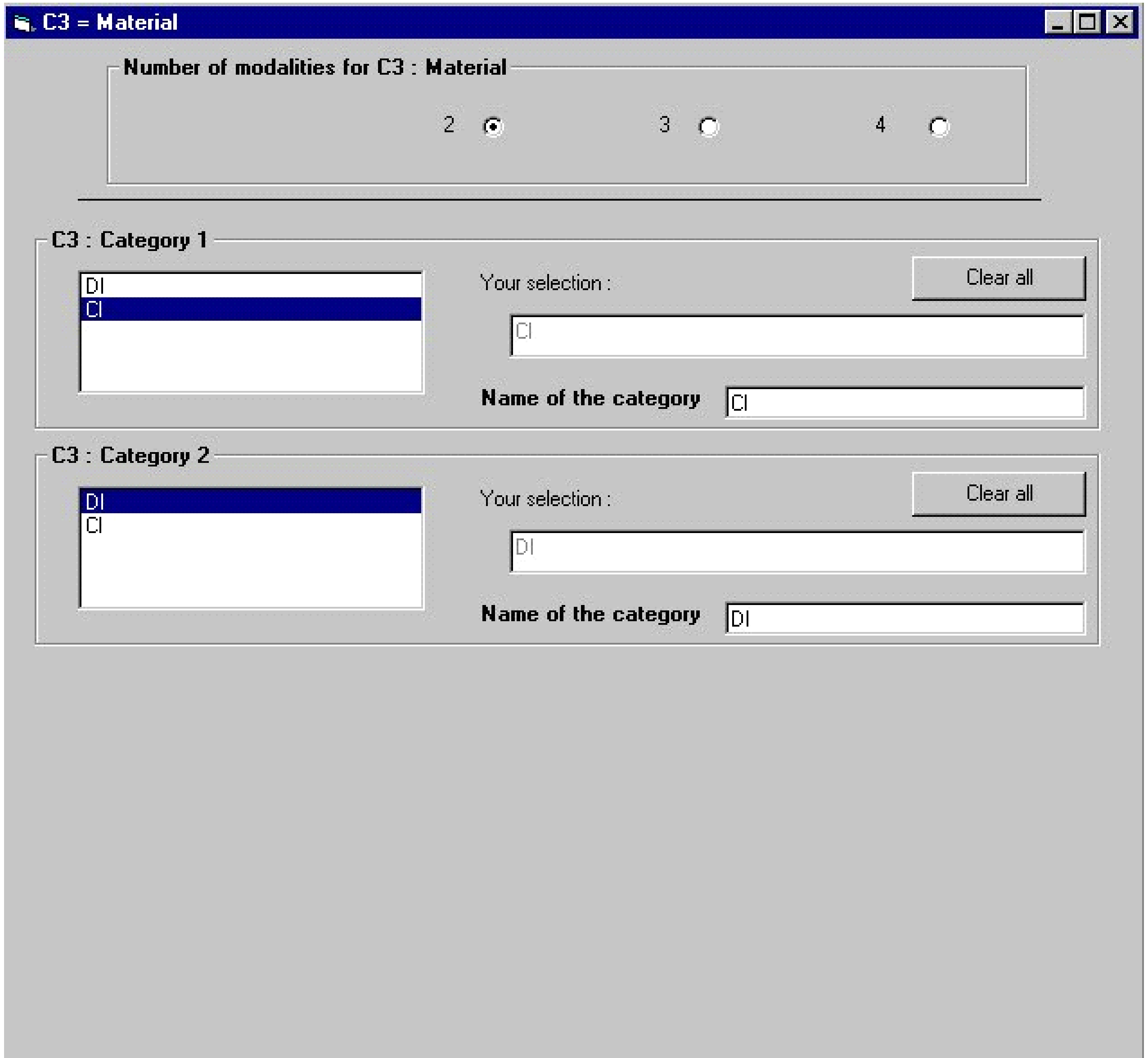
Defined categories can be shown.
The user can cluster som of them to create new ones.


Segment descriptive data
Available data
Do you want to use it ?
With which modalities ?
Yes
No
Yes
No
Done
Segment identification
I2 = Street, road or locality
I3 = Area (municipality or region ...)
Segment characteristics
C1 = Length (m)
C2 = Diameter (mm)
C3 = Material
C4 = Date of installation
C9 = Type of joint
C10 = Depth
Segment environment
E1 = Type of soil
E2 = Traffic in the street or road
E3 = Localisation in the street
E4 = Type of bedding
E5 = Pressure in the segment (MPa)
E6 = Number of service connections
E7 =
E8 =
E9 =
OK

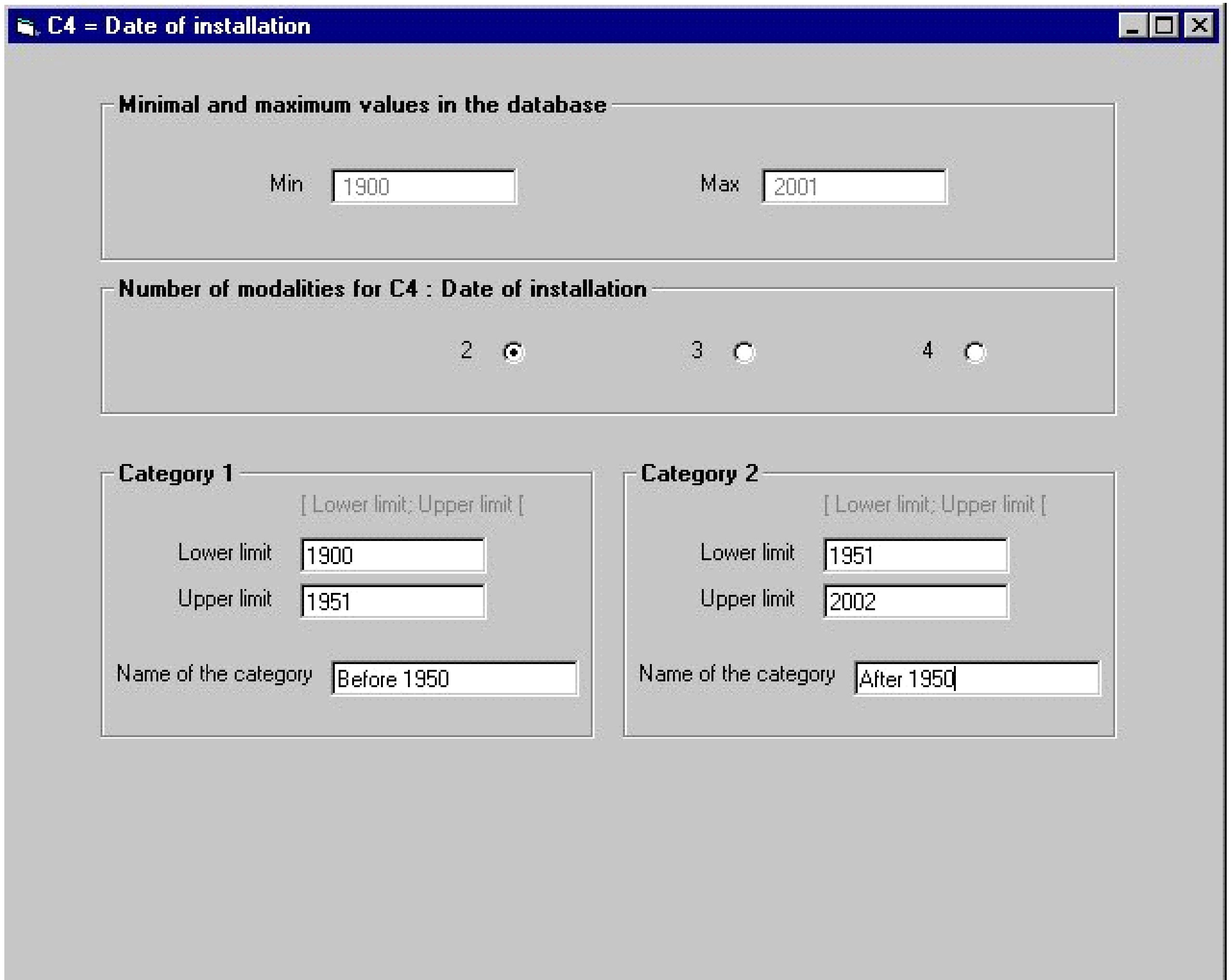

Segment descriptive data
Available data
Do you want to use it ?
With which modalities ?
Yes
No
Yes
No
Done
Segment identification
I2 = Street, road or locality
I3 = Area (municipality or region ...)
Segment characteristics
C1 = Length (m)
C2 = Diameter (mm)
C3 = Material
C4 = Date of installation
C9 = Type of joint
C10 = Depth
Choice of the C2 modalities
Choice of the C3 modalities
Choice of the C4 modalities
Segment environment
E1 = Type of soil
E2 = Traffic in the street or road
E3 = Localisation in the street
E4 = Type of bedding
E5 = Pressure in the segment (MPa)
E6 = Number of service connections
E7 =
E8 =
E9 =
OK

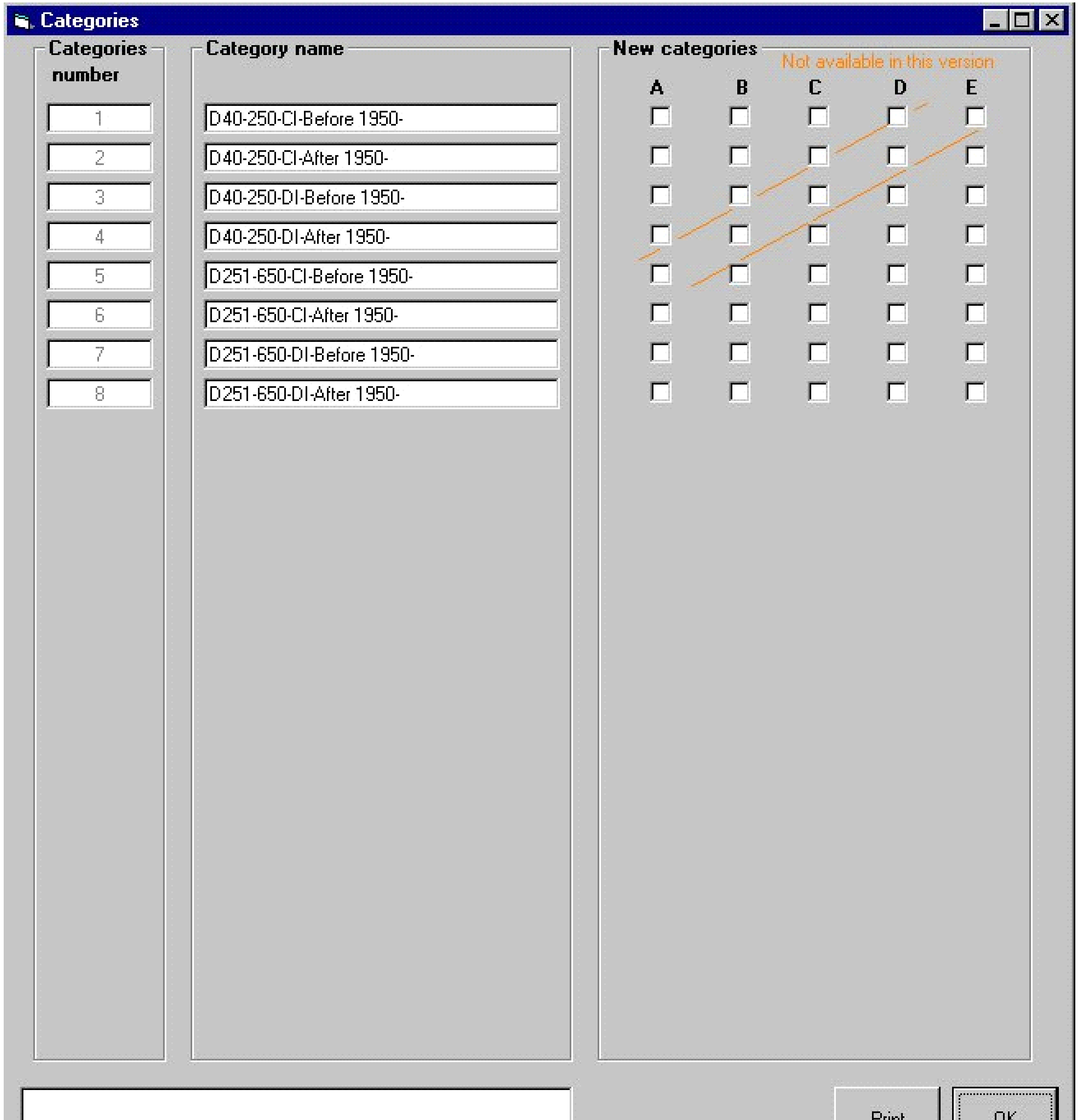

C2 = Diameter (mm)
Minimal and maximum values in the database
Min
40
Max
600
Number of modalities for C2 : Diameter
2
3
4
Category 1
[Lower limit; Upper limit [
Lower limit
40
Upper limit
201
Name of the category
D40-200
Category 2
[Lower limit; Upper limit [
Lower limit
201
Upper limit
601
Name of the category
D201-600
OK


OK

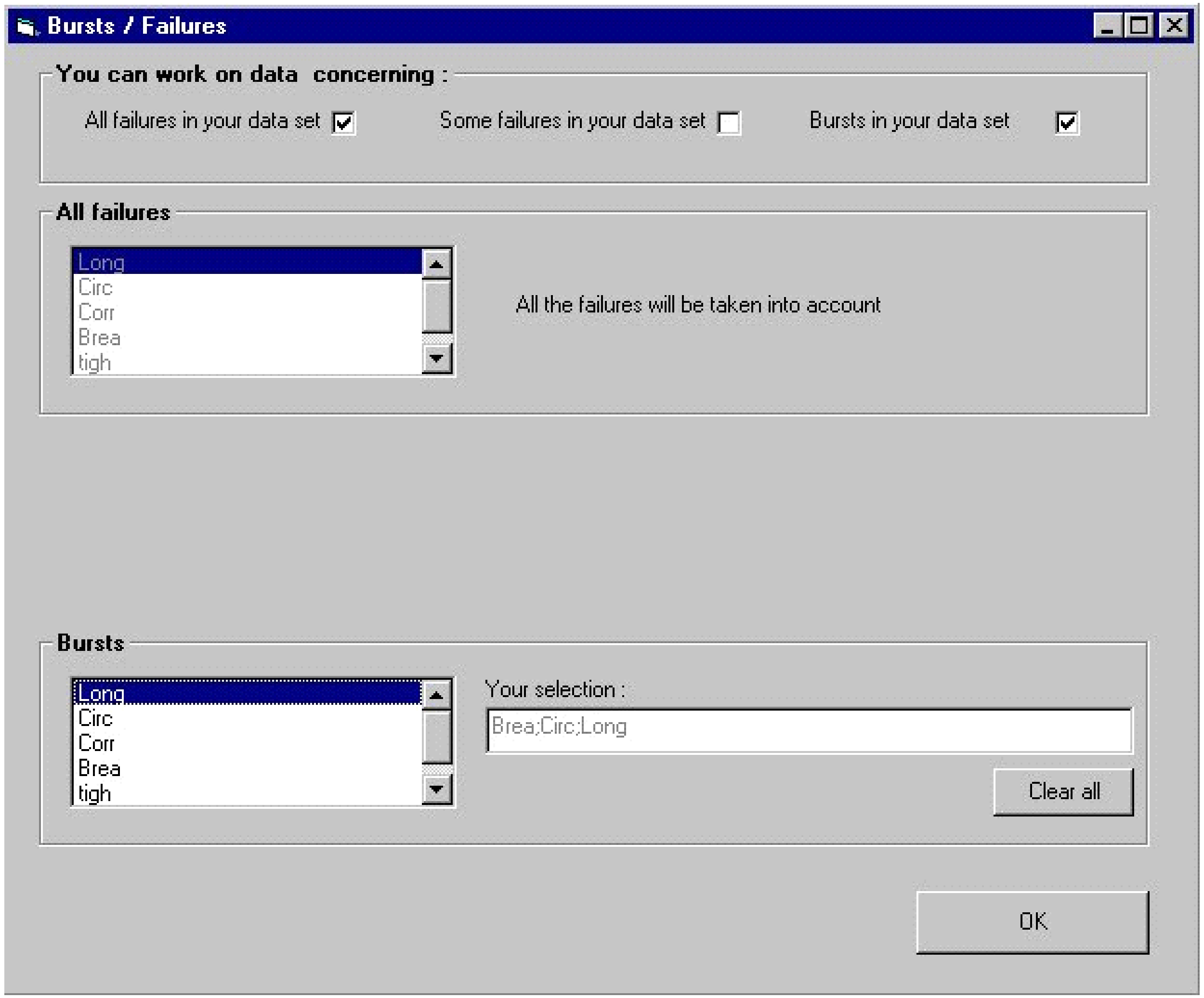

C3 = Material
Number of modalities for C3 : Material
2
3
4
C3 : Category 1
DI
CI
Your selection :
Clear all
CI
Name of the category
CI
C3 : Category 2
DI
CI
Your selection :
Clear all
DI
Name of the category
DI


OK


C4 = Date of installation
Minimal and maximum values in the database
Min 1900
Max 2001
Number of modalities for C4 : Date of installation
2
3
4
Category 1
[Lower limit; Upper limit [
Lower limit 1900
Upper limit 1951
Name of the category Before 1950
Category 2
[Lower limit; Upper limit [
Lower limit 1951
Upper limit 2002
Name of the category After 1950


Categories
Categories number
Category name
New categories
Not available in this version
A
B
C
D
E
1
2
3
4
5
6
7
8
D40-250-CI-Before 1950-
D40-250-CI-After 1950-
D40-250-DI-Before 1950-
D40-250-DI-After 1950-
D251-650-CI-Before 1950-
D251-650-CI-After 1950-
D251-650-DI-Before 1950-
D251-650-DI-After 1950-
Print
OK

BURSTS / FAILURES / … - STEP 3



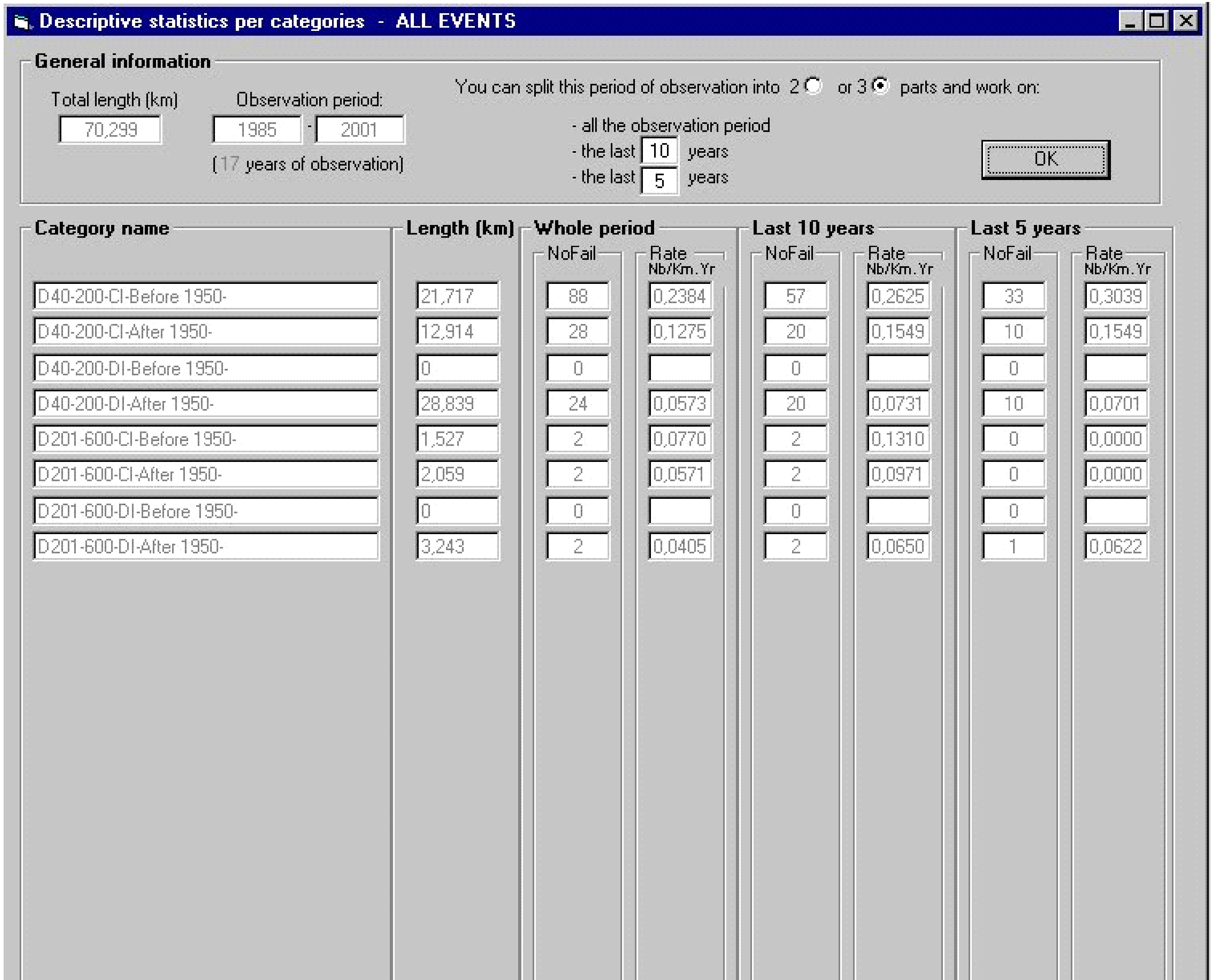
You can chose to work with all failures described in your data set and/or with some failures and/or with only Bursts

If you checked "All failures in your data set", all the failures will be taken into account.

If you checked "Bursts in your data set", You can chose bursts among the possible alternatives available in the data set.

OBSERVATION PERIOD - STEP 4

This window is available for each case studies, i.e. : all failures described in your data set and/or with some failures and/or with only Bursts



Descriptive statistics per categories - ALL EVENTS

General information

Total length (km): 70,299

Observation period: 1985 - 2001

(17 years of observation)

You can split this period of observation into 2 ○ or 3 ◉ parts and work on:

- all the observation period
- the last 10 years
- the last 5 years

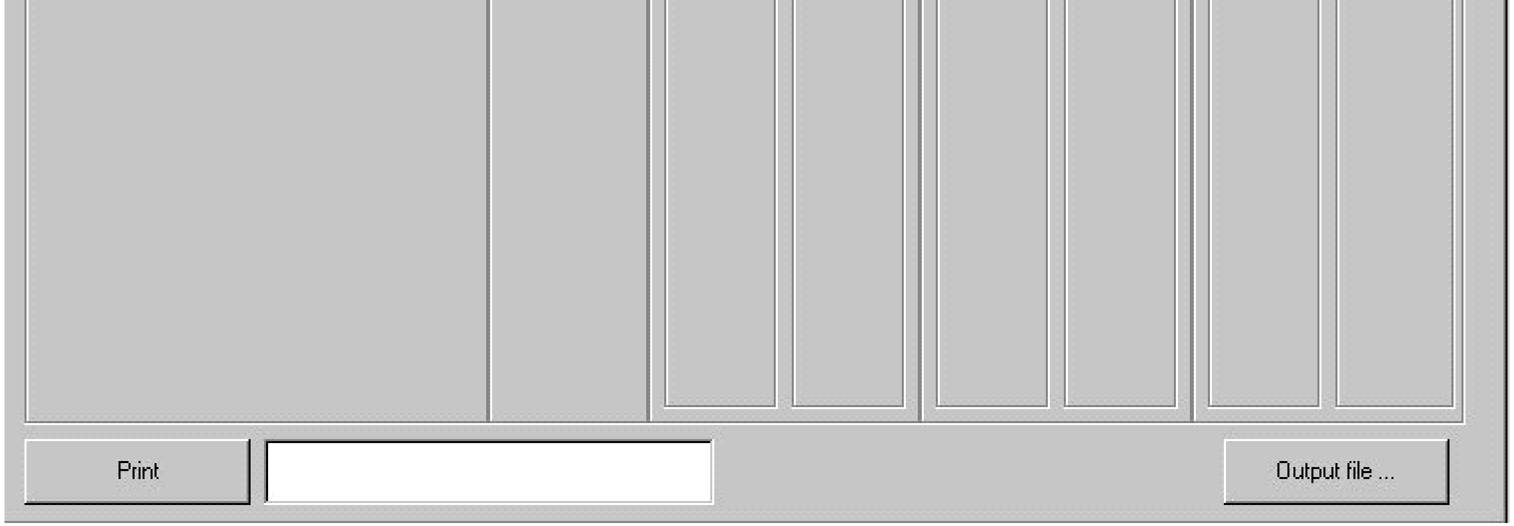
OK

Category name	Length (km)	Whole period NoFail	Whole period Rate Nb/Km.Yr	Last 10 years NoFail	Last 10 years Rate Nb/Km.Yr	Last 5 years NoFail	Last 5 years Rate Nb/Km.Yr
D40-200-CI-Before 1950-	21,717	88	0,2384	57	0,2625	33	0,3039
D40-200-CI-After 1950-	12,914	28	0,1275	20	0,1549	10	0,1549
D40-200-DI-Before 1950-	0	0		0		0	
D40-200-DI-After 1950-	28,839	24	0,0573	20	0,0731	10	0,0701
D201-600-CI-Before 1950-	1,527	2	0,0770	2	0,1310	0	0,0000
D201-600-CI-After 1950-	2,059	2	0,0571	2	0,0971	0	0,0000
D201-600-DI-Before 1950-	0	0		0		0	
D201-600-DI-After 1950-	3,243	2	0,0405	2	0,0650	1	0,0622

You can split the observation period into 2 or 3 parts, and chose them.

Then, for each of the category, and for each period of observation studied, you obtain:

- Total length of pipes (km)
- Total number of evens observed
- The failure rate (No/km/yr)



You can generate output files

OUTPUT FILES

CITY_OUT_FR.TXT

First line:

Pipe Id; FR; 1995;2000; done by KL …

with :
pipe id : User Reference (pipe id)
FR : Failure Rate (observed over the chosen period or calculated by Poisson over the chosen period) (No/km/yr)
« 1995 », « 2000 » chosen period for the calculation of the rate
« done by …. » : free comment

For each pipe:

- User Reference (Pipe Id)
- FR (No./km/yr) = Max[FR(i), FR(j)] i.e., max[Failure Rate pipe (i), Failure rate category(j)] where FR(j) observed or calculated by Poisson Regression Analysis.

CITY_OUT_BR.TXT

First line:

Pipe Id; BR; 1995;2000; done by KL …

with :
pipe id : User Reference (pipe id)
BR : Burst Rate (observed over the chosen period or calculated by Poisson over the chosen period) (No/km/yr)
« 1995 », « 2000 » chosen period for the calculation of the rate
« done by …. » : free comment

For each pipe:

- User Reference (Pipe Id)
- BR (No./km/yr) = Max[BR(i), BR(j)] i.e., max[Burst Rate pipe (i), Burst rate category(j)] where BR(j) observed or calculated by Poisson Regression Analysis.

OUTPUT FILES FOR REGRESSION ANALYSIS

CITY_REG_ANALYSIS.TXT

Output file to statistical analysis (Poisson Regression)

Categorye name	D40-200	D201-600	CI	DI	Before 1950	After 1950	Fail_nber	Exposure
D40-200-CI-Before 1950-	1	0	1	0	1	0	88	369189
D40-200-CI-After 1950-	1	0	1	0	0	1	28	219538
D40-200-DI-Before 1950-	1	0	0	1	1	0	0	0
D40-200-DI-After 1950-	1	0	0	1	0	1	24	418874
D201-600-CI-Before 1950-	0	1	1	0	1	0	2	25959
D201-600-CI-After 1950-	0	1	1	0	0	1	2	35003
D201-600-DI-Before 1950-	0	1	0	1	1	0	0	0
D201-600-DI-After 1950-	0	1	0	1	0	1	2	49406

Poisson Regression

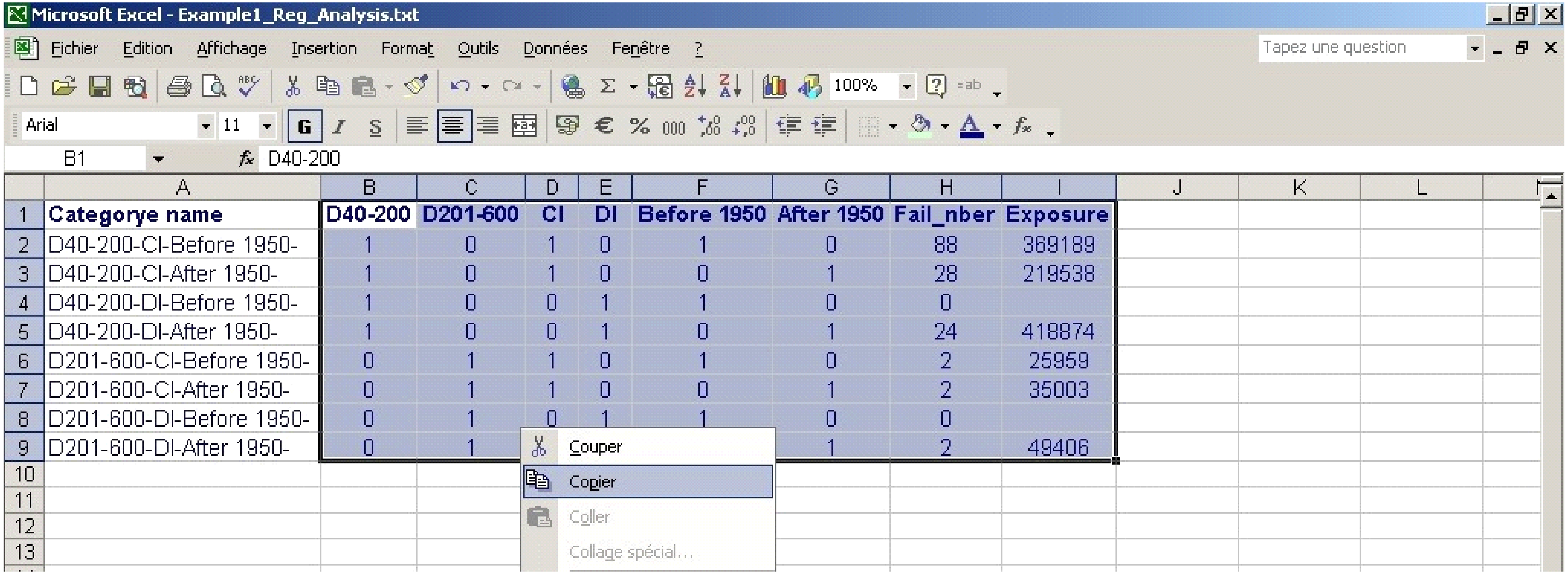
A Poisson regression is a particular form of regression modelling.
A Poisson regression model provides an analysis of the relationship between a count (No of evens) with a Poisson distribution and a set of explanatory variables.
Statistical tests or confidence intervals make it possible to define statistical variables that are significant.

The Poisson regression model is a statistical model, providing a function *g* reflecting the relationship between a dependant variable *y* and the explanatory variables, x1,x2,…,xn, at the level of pipe categories.
The dependant variable is the Number of failures, for a given exposure (km.years). Each category correspond to a set of pipes, and the exposure is a function of length of each section & and the duration of failure records corresponding to this category.

See an example of Poisson regression by STATA software.

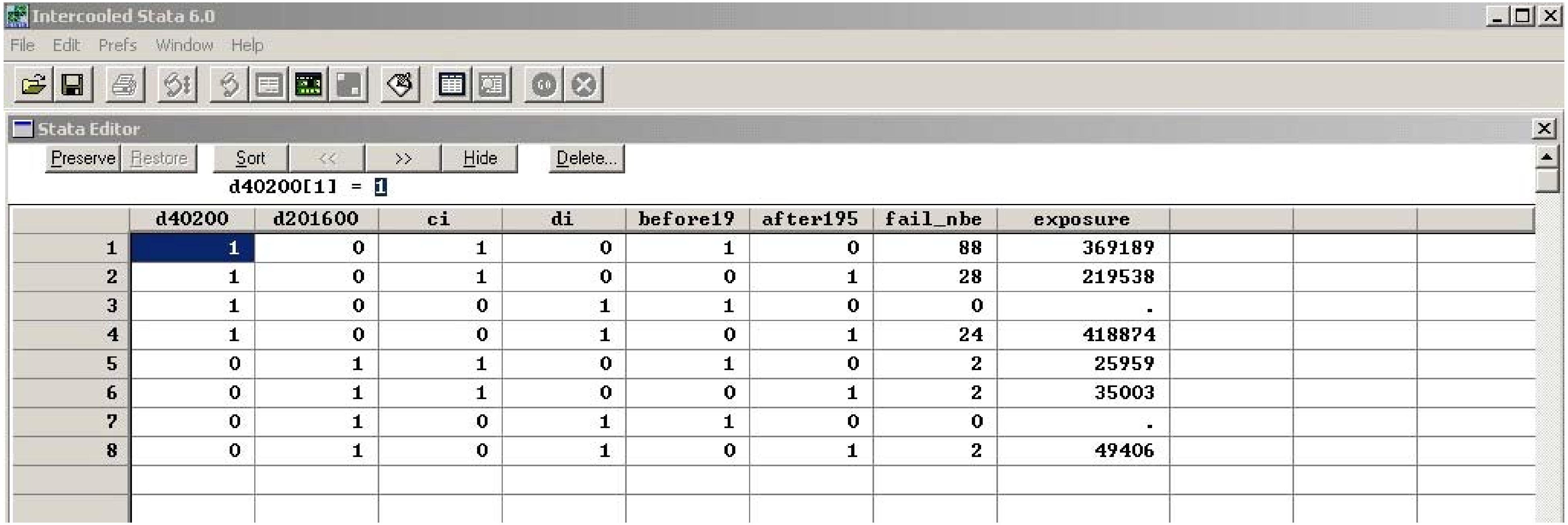
POISSON REGRESSION DONE BY STATA SOFWARE

Step 1: Data formatting for STATA



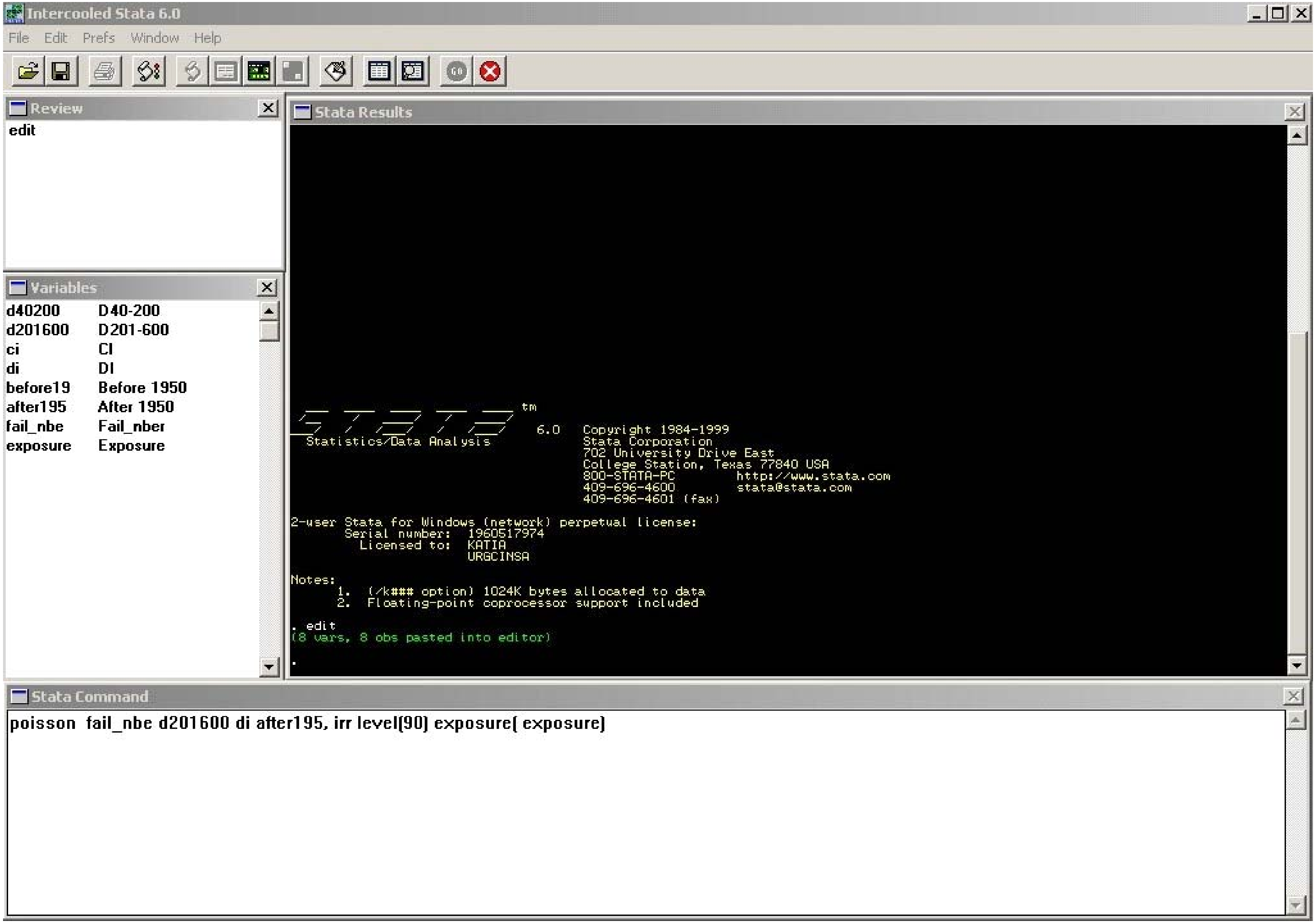
Categorye name	D40-200	D201-600	CI	DI	Before 1950	After 1950	Fail_nber	Exposure
D40-200-CI-Before 1950-	1	0	1	0	1	0	88	369189
D40-200-CI-After 1950-	1	0	1	0	0	1	28	219538
D40-200-DI-Before 1950-	1	0	0	1	1	0	0	
D40-200-DI-After 1950-	1	0	0	1	0	1	24	418874
D201-600-CI-Before 1950-	0	1	1	0	1	0	2	25959
D201-600-CI-After 1950-	0	1	1	0	0	1	2	35003
D201-600-DI-Before 1950-	0	1	0	1	1	0	0	
D201-600-DI-After 1950-	0	1				1	2	49406

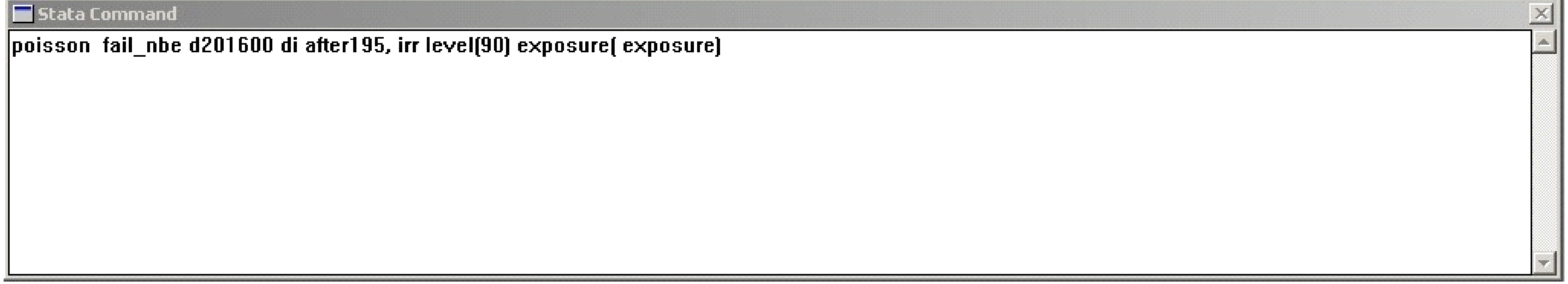
Step 2: Paste the selection in STATA Data Edition



	d40200	d201600	ci	di	before19	after195	fail_nbe	exposure
1	1	0	1	0	1	0	88	369189
2	1	0	1	0	0	1	28	219538
3	1	0	0	1	1	0	0	.
4	1	0	0	1	0	1	24	418874
5	0	1	1	0	1	0	2	25959
6	0	1	1	0	0	1	2	35003
7	0	1	0	1	1	0	0	.
8	0	1	0	1	0	1	2	49406

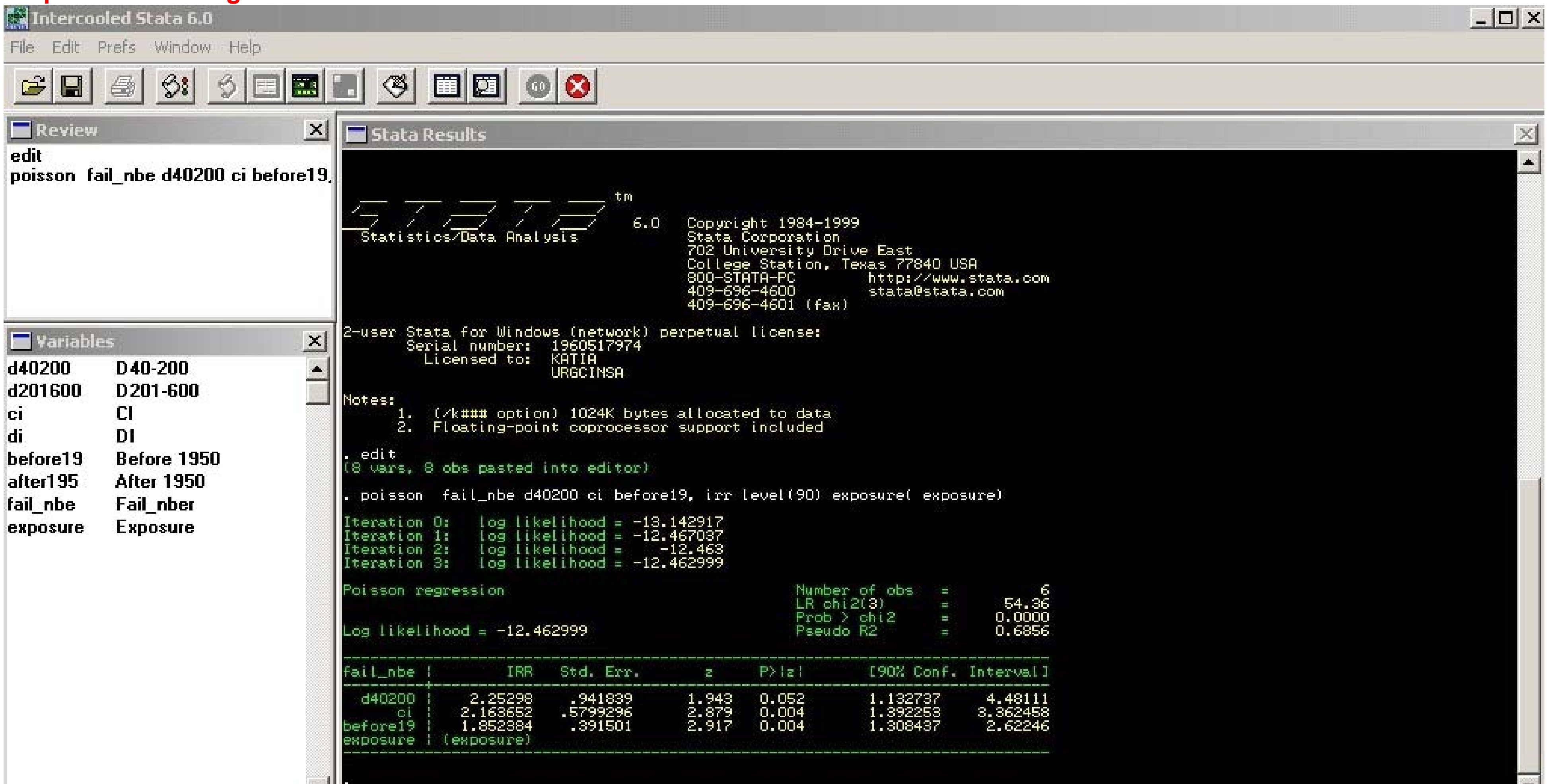
Step 3: Poisson regression order in STATA

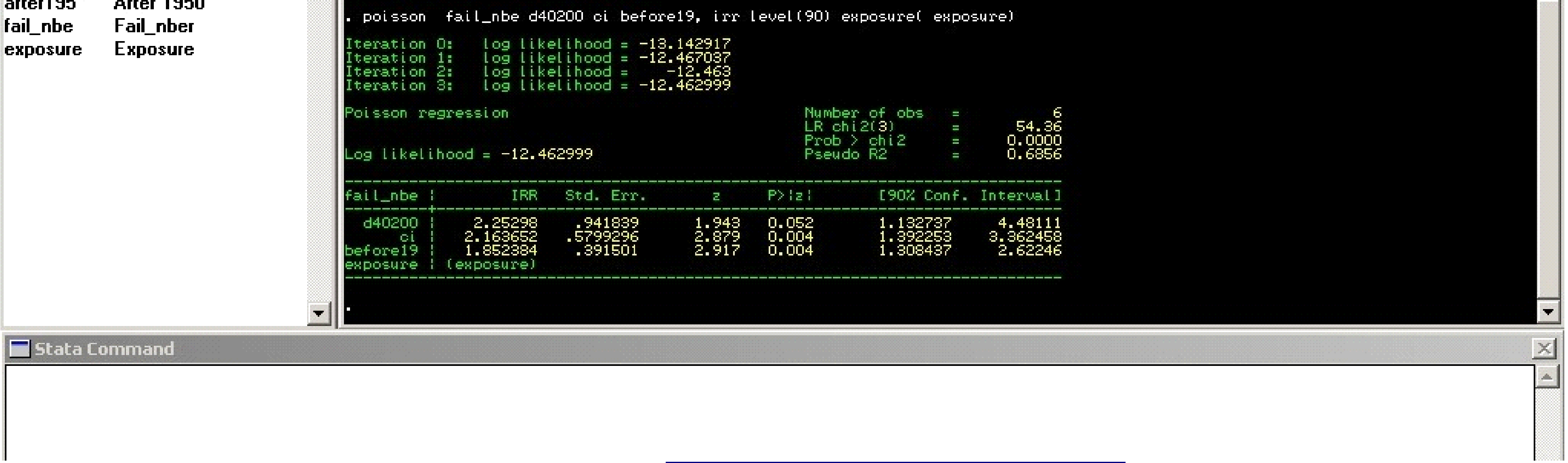

Intercooled Stata 6.0
File Edit Prefs Window Help
Review
edit
Variables
d40200 D40-200
d201600 D201-600
ci CI
di DI
before19 Before 1950
after195 After 1950
fail_nbe Fail_nber
exposure Exposure
Stata Results
tm
6.0 Copyright 1984-1999
Statistics/Data Analysis
Stata Corporation
702 University Drive East
College Station, Texas 77840 USA
800-STATA-PC http://www.stata.com
409-696-4600 stata@stata.com
409-696-4601 (fax)
2-user Stata for Windows (network) perpetual license:
Serial number: 1960517974
Licensed to: KATIA
URGCINSA
Notes:
1. (/k### option) 1024K bytes allocated to data
2. Floating-point coprocessor support included
. edit
(8 vars, 8 obs pasted into editor)
.
Stata Command
poisson fail_nbe d201600 di after195, irr level(90) exposure(exposure)



Poisson estimates a Poisson maximum-likelihood regression of *fail_nbe* on *d40-200, d20-1600, CI, DI …*
irr reports estimated coefficients transformed to incidence rate ratios
level(#) specifies the confident level, in percent, for the confidence intervals.
Exposure(#) specifies a variable that reflects the amount of exposure over which the *fail_nbe* events were observed for each observation

Step 4: Poisson regression order in STATA





	IRR	90% Confidence intervals	
Diameter >200 mm (Ref)	1	-	-
Diameter < 200 mm	2.253	1.133	4.481
Material DI (Ref)	1	-	-
CI	2.164	1.392	3.362
After 1950 (Ref)	1	-	-
Before 1950	1.852	1.308	2.622

Failnet-Reliab Help File

F-Reliab Help

❖ Installation

Copy *F-Reliab_Install.exe* and readme.txt on any folder on your computer.
The EXE file is self extracting just by double-clicking on it and follow the instructions.
All the files will be extracted in the default directory: *c:\F-Reliab*.
This default directory can be changed but it's advised to keep it as it was by default.

❖ Run F-Reliab

To use the application, just double-click on *F-Reliab.exe* in the *c:\F-Reliab* directory.

❖ The F-Reliab procedure

Two Files are used basically in F-Reliab: *hlf file* describing pipes data useful for Hydraulic modelling (including failure rate data) and *ndf file* describing nodes data (including importance of each node).

➢ *Defining initial data for modelling*

These data describe characteristics of the modelling. They are included in the file *config.csv* in the *Files* folder. They concern :

- *the data to be considered for pipe failure rate and node importance,*
  - ***Failure rate considered***

Choosing the "**same failure rate for all the pipes**", failure rate data included in hlf file will not be considered. A common failure rate will be taken into account. By default, the common failure rate is equal to 0.1 failure/km/year.
Choosing "**Individual failure rate**", failure rate data of hlf file will be considered. If these are all equal to 0, the indices will not be calculated.

- ***Node importance***

Choosing "**the same for all the nodes**", Importance node data will be considered and all the nodes will have the same importance.
Choosing "**Individual importance**", importances included in ndf file will be considered. If all of these values are equal to 0, it is considered that all the pipes have the same importance (equal to 1).

- *the type of modelling,*

Choosing "**simple whole network modelling**", only one hydraulic model concerning the whole network will be made. The reliability indices are not computed in this case.
Choosing "**Complete computation of reliability indices**", complete calculation will be made, i.e. as models (with pipe missing) as pipes will be computed and consequently indices calculations.

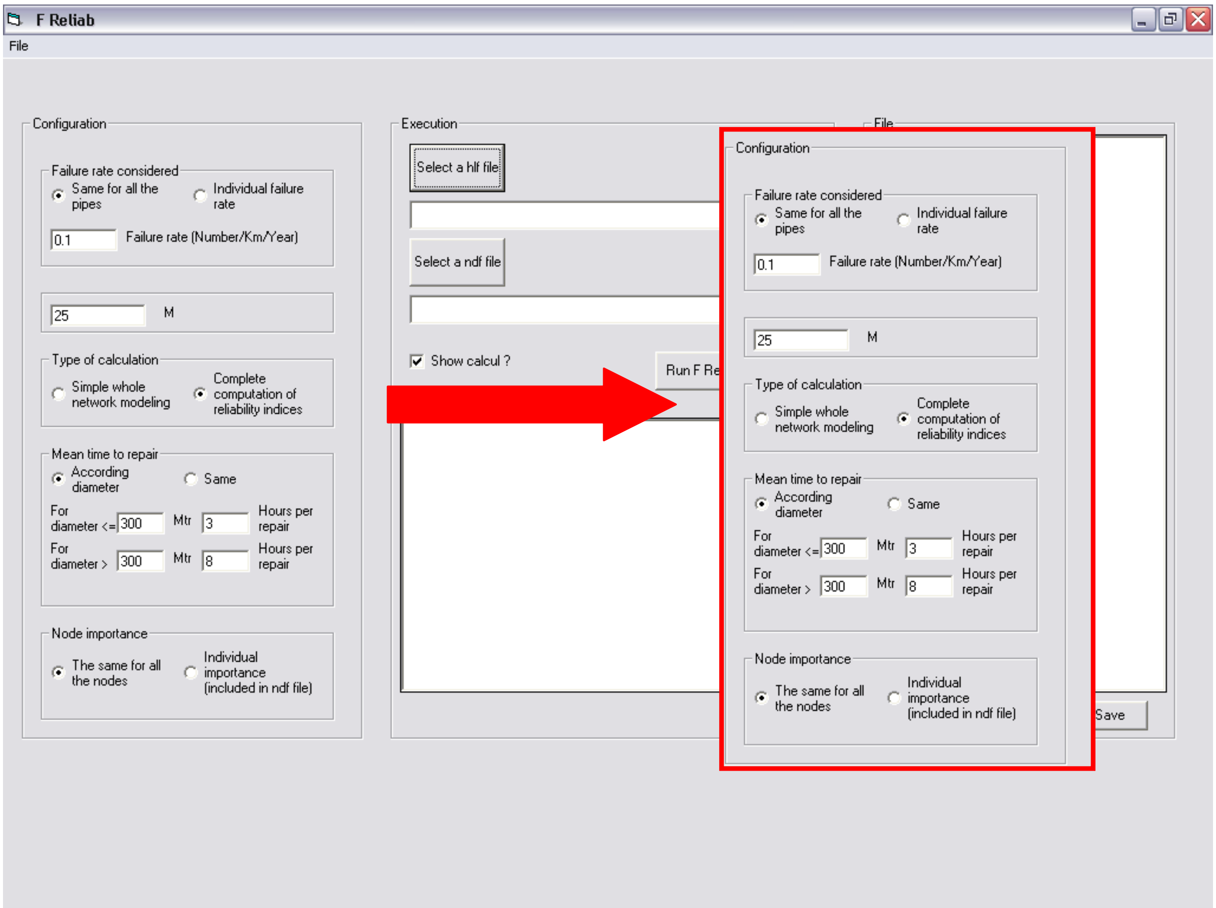
- *the desired pressure,*

This is the critical pressure (in m). Under this value, the available consumption will be less than the demand. By default, this value is equal to 25 m.

- *the time to repair.*

This is the mean time to repair a pipe. This value can be the same for all the pipes (choosing "**same**") or can be dependent of the diameter. By default, the time is equal to:

- 3 hours for pipe diameter less or equal to 300 mm,
- 8 hours for pipe diameter more than 300 mm.



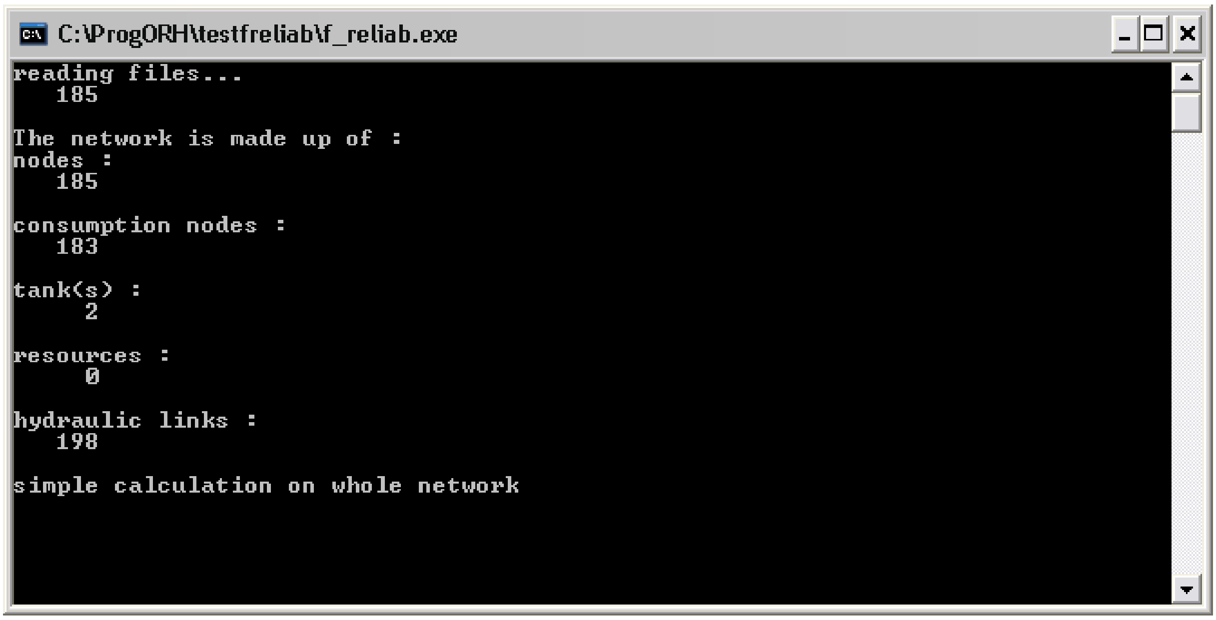
➢ *Run computation*

To run the computation, it is necessary to choose the files that will be modelled. These are :

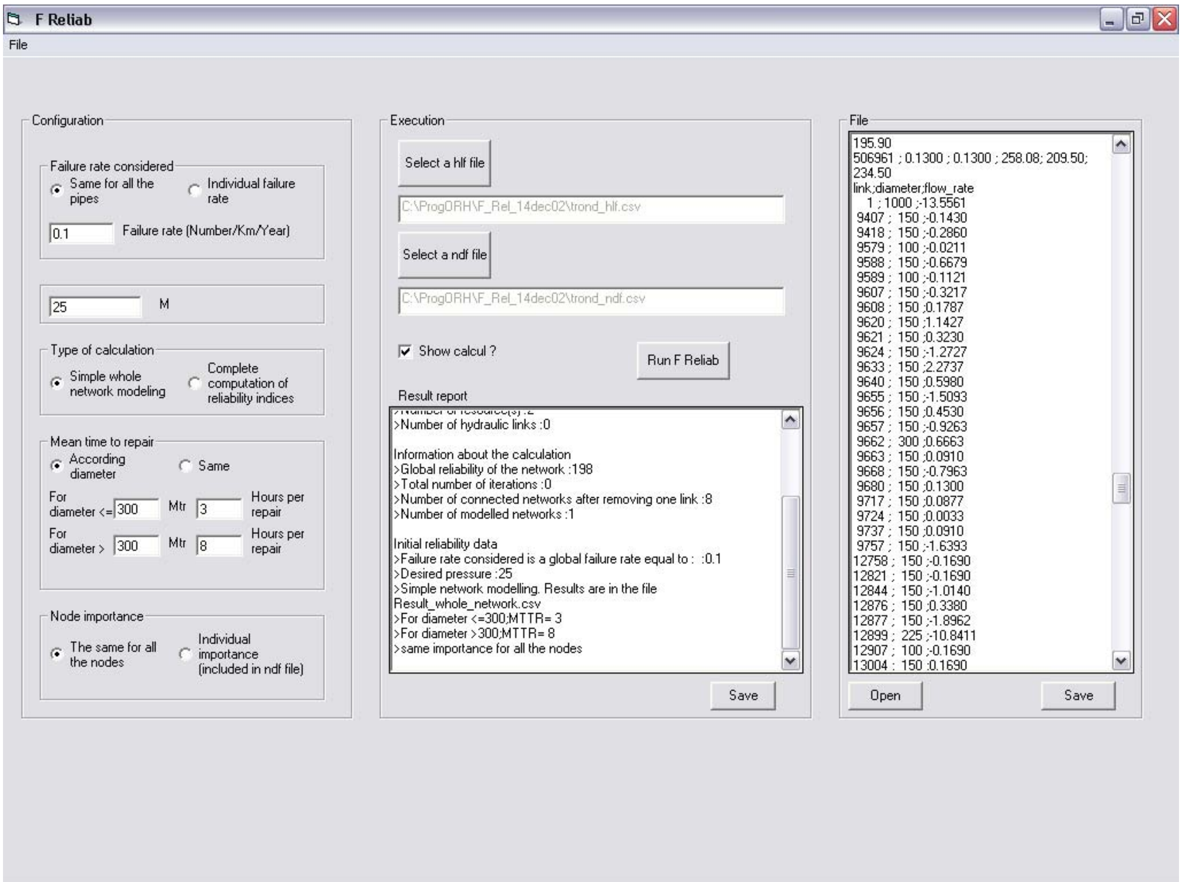
- the hlf file : this describes the hydraulic links (Identifier, node idientifiers, length, diameter, Hazen-Williams roughness coefficient, failure rate),
- the ndf file : this describes the nodes, i.e. :
  * the consumption nodes (Identifier, coordinates, demand in l/s, elevation in m, importance),
  * the tanks (Identifier, water level min and max),
  * the resources (Identifier, water level).

Then click on "***Run F-Reliab"***.

A DOS windows is open and describes the calculation in progress. The modelling is achieved when the DOS windows is closing.



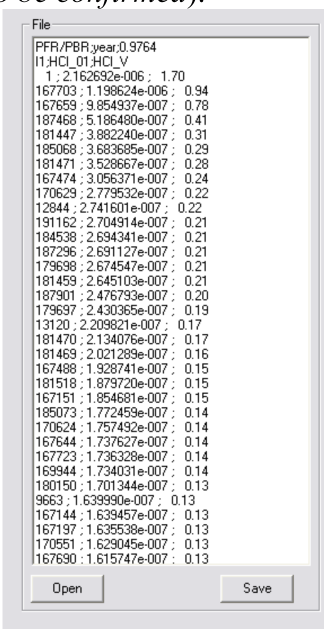
➢ *The results :*



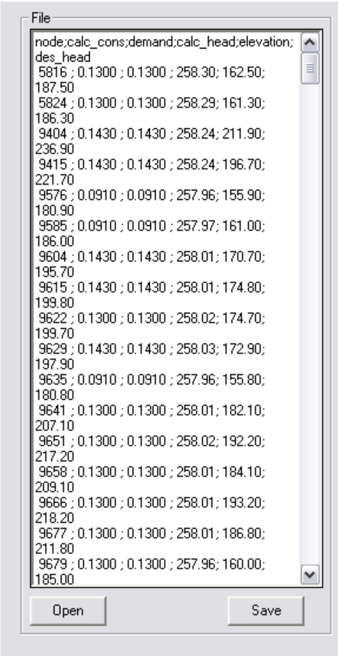
If a complete calculation has been required, results are as in windows below. Two values are computed for each pipe :

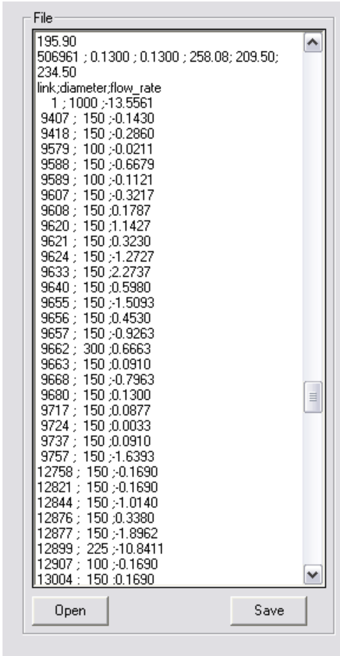
- the Hydraulic criticality index (HCI, between 0 and 1) useful for ARP,
- the volume non-supplied caused by failure risk (HCI_V in m^3).

The pipes are sorted according to the HCI. This file can be saved in with a formatted CARE-W name : *Cityfnr.txt* (*or city.fnr, to be confirmed*).



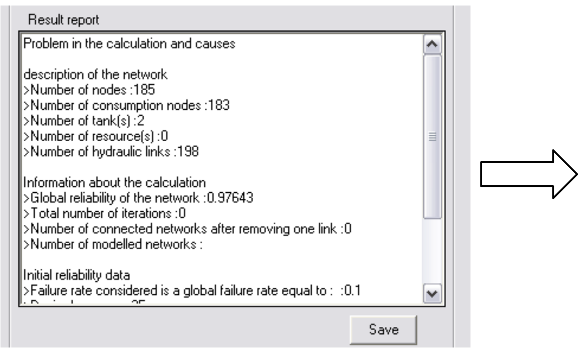
If a simple whole network modelling has been required, the results are as in window below. These provide results about links (flow rate) and about nodes (available consumptions and pressures).





A report of the calculation is also proposed. It informs about :

- problems in the calculation,
- a summary description of the network,
- a summary description of the calculation,
- a summary description of initial data.



Problem in the calculation and causes

description of the network
>Number of nodes :185
>Number of consumption nodes :183
>Number of tank(s) :2
>Number of resource(s) :0
>Number of hydraulic links :198

Information about the calculation
>Global reliability of the network :0.97643
>Total number of iterations :0
>Number of connected networks after removing one link :0
>Number of modelled networks :

Initial reliability data
>Failure rate considered is a global failure rate equal to : :0.1
>Desired pressure :25
>Simple network modelling. Results are in the file Result_whole_network.csv
>For diameter <=300;MTTR= 3
>For diameter >300;MTTR= 8
>same importance for all the nodes

❖ The files used in F_Reliab

➢ *Organisations of the files*

Several types of files are used in F-RELIAB:

- *Input files,*

To run the analysis, it is necessary to choose the files that will be modelled. These are :

- the hlf file : this describes the hydraulic links (Identifier, node idientifiers, coordinates, length, diameter, Hazen-Williams roughness coefficient, failure rate),
- the ndf file : this describes the nodes, i.e. :
  * the consumption nodes (Identifier, demand in l/s, elevation, importance),
  * the tanks (Identifier, water level min and max),
  * the resources (Identifier, water level).

- *Output files,*

After computing, several output files are available:

Frel_output.csv : it provides the calculation reliability indices results,
Result_whole_network.csv : it provides results of a simple whole network modelling,
report.csv : provides information about the modelling.

The forecast result can be saved in Care-W format. The name of the output file has to follow this standard : *Cityfnr.txt* (*or city.fnr, to be confirmed*).

- *Initial files,*

There are two initially files :

Config.csv : provides the initial data for the modelling,
translate.ini : provides all command name of F_Reliab in a specific language (English by default)

- *Language files,*

These files allow the change of F_Reliab command language. You can create a new language file using the menu "**File Translate\Make a translation file**" and use it choosing "**File Translate\Use a translation file**".

- *Exe files*

One sub-program is used in F-Reliab : *F_Reliab_prog.exe* .

❖ To contact us

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Relnet Help File

Contents

About

RelNet 2.00 is a specialised program designed and developed at the Institute of Municipal Water Management,Faculty of Civil Engeneering, Brno University of Technology.

RelNet calculates an impact of each pipe link on the total network reliability.

RelNet is based on Epanet computing core. As an input it requires *.inp files, which are produced by Epanet Export Network function.

The output value is **HCI (Hydraulic Critical Index)** - an impact of each pipe link on the total network reliability. Since the ver. 1.84, this value is calculated from the undelivered volume of water at required pressure.

Input : Epanet network
Output : HCI - Indicator Ph14b - Impact of j-th pipe link on the total network reliability.The range is <0,1>.

Installation

Plain simple:
Run installer and select the destination folder. An RelNet item will be added to your Windows "Start menu"
If you receive zipped distribution, just extract everything into the folder of your choice and run the Relnet.exe.
There is and folder under the Relnet installation directory. Use this folder to store your computing data.
This folder is also necessary for data exchange between CARE-W prototype and RelNet.

The installation package includes:

- RelNet.exe - application
- Relnet.hlp - help file
- Relnet.cnt - help file
- Epanet2.dll - dynamic linked library
- Test.inp - sample network

All those files are necessary for running RelNet.

Upgrade

If you used installer to install RelNet, go to Start > Settings > Control Panel > Add remove programs and uninstall previous version.
Then run installer of the new version.
If you used Relnet distributed in .zip format then open a .zip file and overwrite files in the existing installation folder.

Upgrade

If you used installer to install RelNet, go to Start > Settings > Control Panel > Add remove programs and uninstall previous version.
Then run installer of the new version.
If you used Relnet distributed in .zip format then open a .zip file and overwrite files in the existing installation folder.

Uninstall

Distribution with a installer :
Go to Start > Settings > Control Panel > Add remove programs and uninstall.

ZIP file distribution :
Even more simple:
Just delete everything in the installation folder. There are no registry entries, installed dll's or likewise.

Running Relnet

RelNet is a stand-alone Win32 application running under Win 9x,NT,W2k and XP. It was successfully tested on all platforms. RelNet is programmed in Borland Delphi 7 under Win XP. RelNet requires an Epanet computation core (epanet2.dll). It's distributed within the RelNet. We recommend downloading an Epanet 2.0 for Windows to create and test input files prior to running under RelNet.

Epanet download location and info : http://www.epa.gov/ORD/NRMRL/wswrd/epanet.html

Using Relnet

1. Create network in Epanet.

2. Try to run an analysis.

3. If successful,export it to *.inp. If not, review your network.

4. Once you are happy with your network analysis in Epanet you can proceed to run RelNet.

5. Run the RelNet.exe

6. Create a separate folder for each network under the installation directory (example : ...)

7. Put the *.inp file into the created folder.This will become the working directory,you will find all the results and working files there. Make sure that all other files in the directory (i.e. results an working files of previous calculations) are deleted before the new calculation is started.

8. Click "Load file",locate desired *.inp file in the working directory and click "Open".

9. You will be notified when the file has been successfully loaded.

10. Now proceed to "Link processing". This step will discard one link of a network in each step of the analysis and create a new map of the network. The continuity of the network is then tested. If the network is not continuous, the nodes and links that are not connected to a water source are discarded from the network diagram. The input file for the hydraulic analysis is created.A number of files equal to the number of links in the network will be generated in this step. The file mask is out.inp-link-xx, where xx is the index of the discarded link. Proceed to the next step.

11. **"Pressure processing"** creates output files with the results of the hydraulic analysis using the EPANET 2.0. The output files are saved in the working directory with the following file mask: !out.inp-link-xx-. Each file contains the node ID and calculated pressure separated by a semicolon. xx is the index of the discarded link.
Proceed to the next step.

12.**"HCI (Hydraulic Critical Index) processing"** calculates the impact of each pipe link on the total network reliability.

Required pressure H_req:
You must enter a required available pressure in metres. This must be an integer number greater then 0 and also higher then minimum pressure. The recommended value is 25 (according to the local requirements). This value will be applied across all nodes. See step 12.3. for full description.

Minimum pressure H_min:
An hydraulic pressure under which we assume that the consumer demand is not satisfied at all and the amount of delivered water is 0 in this node. See step 12.3. for full description.

The output file with the calculated value of HCI is saved in the working directory with the input file. It has the same name as the input file, but with "rel" extension. An MS Excel workbook (*.xls), containing the HCI values, is also created. There is a text file with the same name as the input file, but with ".log" extension. This file contains reports of any errors of hydraulic processing.

HCI processing - algorithm description

12.1. Calculation of actual head pressure and demand in the each node in the network, in the original state of the network diagram. None of the pipe links is discarded. Results are Q_act (actual demand), H_act (actual pressure) and sum of Q (Q_total).

12.2. One pipe link is discarded. The network pressure analysis and calculation of pressure in each node (H_new) and calculation of demand (Q) is realized.

12.3. Description of HCI calculation :
HCI of the discarded link is calculated from the volume of undelivered water in the entire network. The amount of undelivered water in each node depends on the calculated pressure value (H_new).

- if H_new < H_min then Q_new = 0
If the H_new value is lower than H_min we assume that the consumer demand is not satisfied and the amount of delivered water is 0 in this node.

- if 15 < H_new < H_req (25 m recommended) then the amount of delivered water in the node is reduced and is calculated according to the following formula:

$$Q\_new = Q\_act \cdot \frac{\sqrt{H\_new}}{\sqrt{H\_act}}$$

- if H_new > H_req (25 m recommended) then the consumer demand is fully satisfied and delivered water Q_new = Q_act (nothing has changed).

Delivered water Q_new is calculated by this method for each node of the network.

12.4. HCI calculation

The total sum of Q_new is calculated over all nodes of the entire network.
Then the HCI is calculated according to the following formula:

$$HCI = \frac{Q\_total - sum(Q\_new)}{Q\_total}$$

A higher value of HCI means a higher impact of the discarded link on the total network reliability. If the sum of Q_new = 0 then no demand is satisfied in all nodes of the network and HCI = 1.

If sum of Q_new=Q_total, HCI = 0 then demand is fully satisfied at the required pressure.

<u>Output text file and Ms Excel contain these values,in the following order :</u>

LinkID;RemovedNodes;Nodes<RP;HCI

LinkID - the identification of discarded link
RemovedNodes - the number of discarded nodes during the "Link processing". This value presents the number of disconnected (not supplied) nodes, if a particular link is discarded.
Nodes<RP- this value presents the number of nodes that have lower pressure than the required pressure (the value given from the "HCI Processing" stage)
HCI (Hydraulic Critical Index)- Indicator Ph14b - the impact of j-th pipe link on the total network reliability. The range is <0,1>. If the pressure of all nodes is higher than required pressure (RP) and none of the nodes was disconnected, the value is equal to 0.

After processing you can open the results file using MS Excel. This allows sorting and other useful manipulation.

All this information is also displayed in a grid in the main application window.

Index-ID Export

Because of internal coding of links, there is a function, which creates a .txt file containing indexes and ID's for all links in the network. See step 10 - the file mask contains xx, which is the index of the discarded link. If you would like to know the specific ID for this link index, you have to look into the "Index-ID Export" file.

Special precautions - READ !!!!

Known limitations :

Since version 2.00 all functions of Epanet network .inp file all supported (controls,valves,rules...).

Please, be aware if using [Controls] and [Rules] sections of Epanet file. There are some strict formating conditions, which are necessary
for successful calculation of hydraulics.

Example :

[CONTROLS]
LINK 7 CLOSED IF NODE 9 ABOVE 20
LINK 1 CLOSED AT TIME 0

Put only one space between words and numbers. Don't use tabs. No empty lines between conditions.

[RULES]
RULE 1
IF JUNCTION 3 PRESSURE > 20
AND JUNCTION 5 PRESSURE > 17
THEN PIPE 5 STATUS IS CLOSED
AND PIPE 3 STATUS IS CLOSED

RULE 2
IF JUNCTION 5 PRESSURE > 17
THEN PIPE 7 STATUS IS CLOSED

IF..THEN,IF..THEN..AND,IF..AND..THEN,IF..AND..THEN..AND are supported. Put only one space between words and numbers. Don't use tabs. No empty lines between conditions.

We have successfully tested RelNet on the large networks with 2000+ nodes and pipes. You should expect long lasting operation when calculating large networks and also lot's of free disk space is required.
(2000 nodes use approx. 1GB and take 1 hour to compute on PIII machine).

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