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AUTOMATIC GENERATION OF ROAD NETWORK MATRICES AND HOMOGENEOUS SECTIONS FOR USE IN HDM-4

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Summary

This paper describes the development of automatic processes (based on the dynamic segmentation techniques) to generate road network matrices and homogeneous sections for use in road planning analyses within the Highway Management and Development (HDM-4) model. These processes are used to transfer data stored in the relational Road Management System (RMS) database managed by the Namibian Road Authority in an efficient and effective manner.

In order to simplify the process of performing a strategy analysis for an entire road network, HDM-4 employs the concept of a road network matrix. This matrix consists of a number of representative road sections, which reflect the various types of road which exist in the relevant road network. Each representative section is defined in terms of a number of key attributes that most influence pavement performance and road user costs. For tactical economic analyses, HDM-4 uses the concept of homogeneous sections. These are physical sections of the network for which all road characteristics are constant. The current version of HDM-4 does not include a process that can be used to automatically generate a road network matrix or homogeneous sections, and users are required to do this externally. However, both the creation of a road network matrix, and the conversion of a network into homogenous sections are often cumbersome, particularly when the source network consists of thousands of kilometres of road sections.

Amongst other benefits, this automatic data transfer tool has enabled the Roads Authority staff to produce a representative matrix for strategic planning analysis of a road network that consists of 17,694 basic segments in a few minutes, instead of the usual weeks if not months that it takes to derive it manually. This tool does not only provide the Road Authority in Namibia with a flexible tool that can assist them in the definition of their road network maintenance programmes, but it also significantly reduces the amount of time used for data preparation and analysis and consequently cost.

This is approach is viewed the best way forward for achieving an efficient and effective integration between existing Pavement Management Systems and the HDM-4 model.

KEY WORDS: AUTOMATIC / ROAD / SECTION / NETWORK / MATRIX / HOMOGENEOUS.

1. INTRODUCTION

This paper describes the development of the data transfer tool encapsulating the automatic processes for generating road matrices and homogeneous sections for use in the Highway Development and Management (HDM-4) model. This work was carried out as part of the overall integration project aimed at linking HDM-4 with the existing Namibian Road Management System (RMS) via a Network Integration Module (NIM). The NIM system provides the overall framework for the management of the Namibian national road network. Senior policy makers and road managers within the Namibian Roads Authority require relevant and up to date information in order to analyse and to justify longer-term strategies. These automatic processes provide the overall RMS system with the capability to link up with HDM-4 in a quick and effective manner hence supporting such needs in an efficient mode.

These processes are part of a global integration tool that includes data import from the RMS to HDM-4 as well as export of analyses results from HDM-4 back to the RMS system as Figure 1 shows. Only the first part of the integration is discussed in this paper.

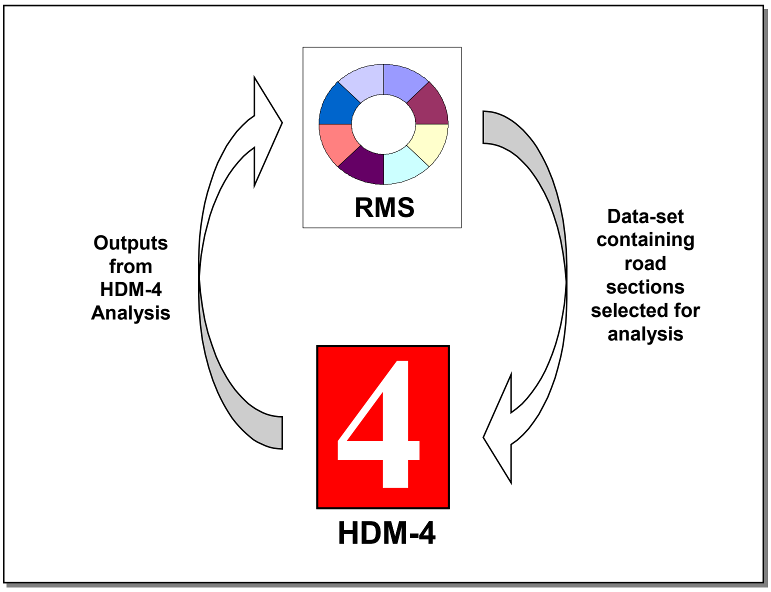


Figure 1- Data-Flow between RMS and HDM-4

HDM-4, is the successor to the World Bank Highway Design and Maintenance Standards Model (HDM-III). The new HDM-4 is a powerful system for the analysis of road management and investment alternatives. It incorporates three dedicated applications tools for project level analysis, roadwork programming under constrained budgets, and for strategic planning of long-term network performance and expenditure needs. It is designed to be used as a decision-support tool within a road management system hence its integration within the Namibian system for use at network level.

However, experience has shown that preparing data for HDM-4 for network analyses is not straightforward and could take weeks if not months to get the information in the format required by the model. The main reason for this is that HDM-4 has very particular data input requirements. The main problems involved in transferring road network data from existing databases into HDM-4 are that the latter applies the concepts of a road network matrix (for strategic analyses) and homogeneous sections (for tactical analyses).

Both road matrix elements and homogeneous sections comprise categories of the road network defined according to the key attributes that most influence pavement performance and road user costs. Although it is possible to model basic individual road sections in a strategic or tactical analysis application, it is cumbersome to individually model each road segment as a network may include thousands of kilometres of roads. In the case of Namibia, the entire road network consists of 17694 standard segments of 500 meters each.

Generally, a sophisticated piece of software is required to fulfil these requirements, and to establish a sustainable link between HDM-4 and the road database. The following sections describe the various steps involved in the development of this tool that manages the automatic generation of road network matrices and homogeneous sections for network analyses. Figure 2 gives an overview of the phases involved in the automatic generation of these HDM-4 data-sets.

The above tool is implemented as part of the Namibian Network Integration Module (NIM) between HDM-4 and the RMS database and is used as the main data preparation system for network maintenance planning. The NIM user interface is implemented as a step-by-step wizard that guides the user in the preparation of the HDM-4 network data.

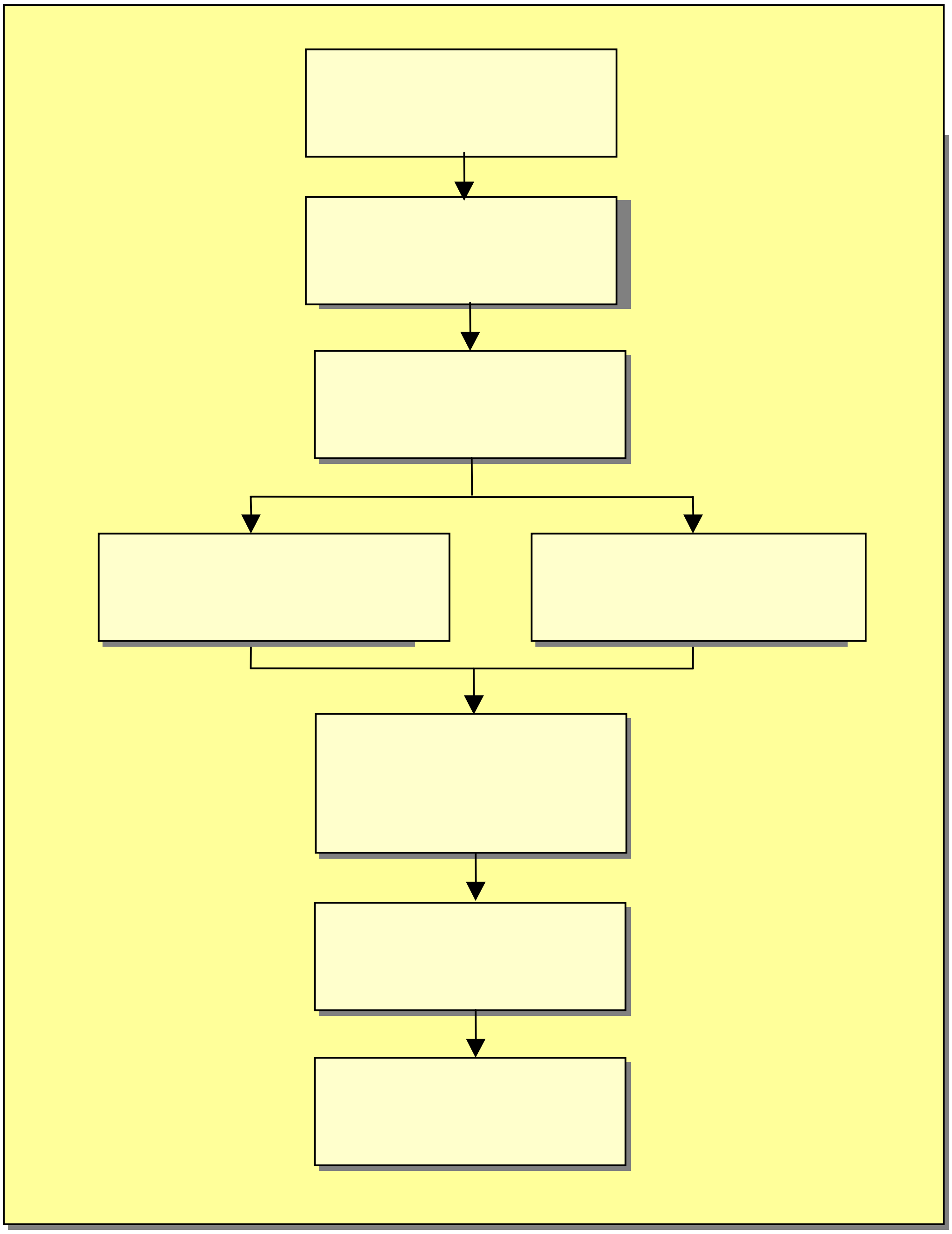


Figure 2 - Overview of the automatic generation of HDM-4 data-sets

2. DESCRIPTION OF THE AUTOMATIC GENERATION PROCESS

2.1 Definition of Attributes that most influence performance and RUCs.

The first step in the process of generating the HDM-4 input data is the selection of those attributes that most influence pavement performance or road user cost. This is done through a free-form query (see Figure 3) with a list of up to 22 attributes for both paved and unsealed roads. For each attribute, the user defines the various categories of allowable values and their value bands (e.g. traffic, strength, condition, etc…). The user may change or modify those attributes at any time during the automatic generation process.

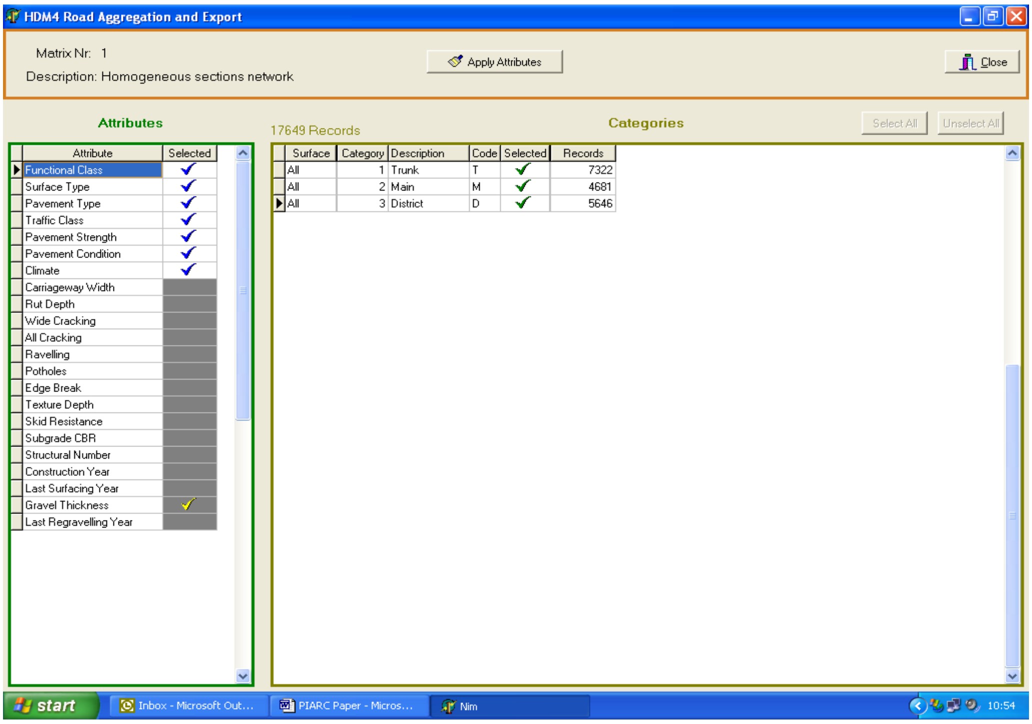


Figure 3: Freeform query for selecting pavement attributes

With the above wizard, the user is able to select from the following attributes and predefine the attribute categories and associated value bands:

- Functional Class (Trunk; Main; District)
- Surface Type (Bituminous; Unsealed)
- Pavement Type (e.g. Asphalt Mix on Asphalt Base (AMAB); etc..)
- Traffic Class (e.g. High; Medium; Low)
- Pavement Strength- Deflection (e.g. Strong; Acceptable; Warning)
- Pavement Condition (e.g. Good; Fair; Poor)
- Climate (e.g. Semi-arid; Sub-humid; Humid; Per-humid)
- Carriageway Width (e.g. Standard; Narrow)
- Rut Depth (e.g. Good; Fair; Poor)
- All Cracking (e.g. Good; Fair; Poor)
- Wide Cracking (e.g. Good; Fair; Poor)
- Ravelling (e.g. Good; Fair; Poor)
- Potholes (e.g. Good; Fair; Poor)
- Edge Break (e.g. Good; Fair; Poor)
- Texture Depth (Coarse; Medium; Fine)
- Skid Resistance (e.g. Good; Fair; Poor)
- Subgrade CBR (e.g. Good; Fair; Poor)
- Structural Number (e.g. Strong; Acceptable; Warning)
- Construction Year (Young; Medium; Old)
- Last Surfacing Year (Young; Medium; Old)
- Gravel Thickness (Thin; Medium; Thick)
- Last Regravelling Year (Young; Old)

The principal "rule-of-thumb" when selecting which attributes to be used, is that the more attributes selected, the finer the subsequent analysis will be. However, in deciding the number attributes to be used, the user should bear-in-mind that more attributes will increase the matrix size or the number of homogeneous sections and consequently slow-down the analysis and makes results exploitation more cumbersome.

2.2 Selection of Sections to be Analysed in HDM-4

The second step in the process of generating HDM-4 data-sets is the user selection of the road sections that he/she wishes to analyse in HDM-4. This choice will depend largely upon the type of analysis to be performed and it is done using the Predefined Sets wizard (see Figure 4).

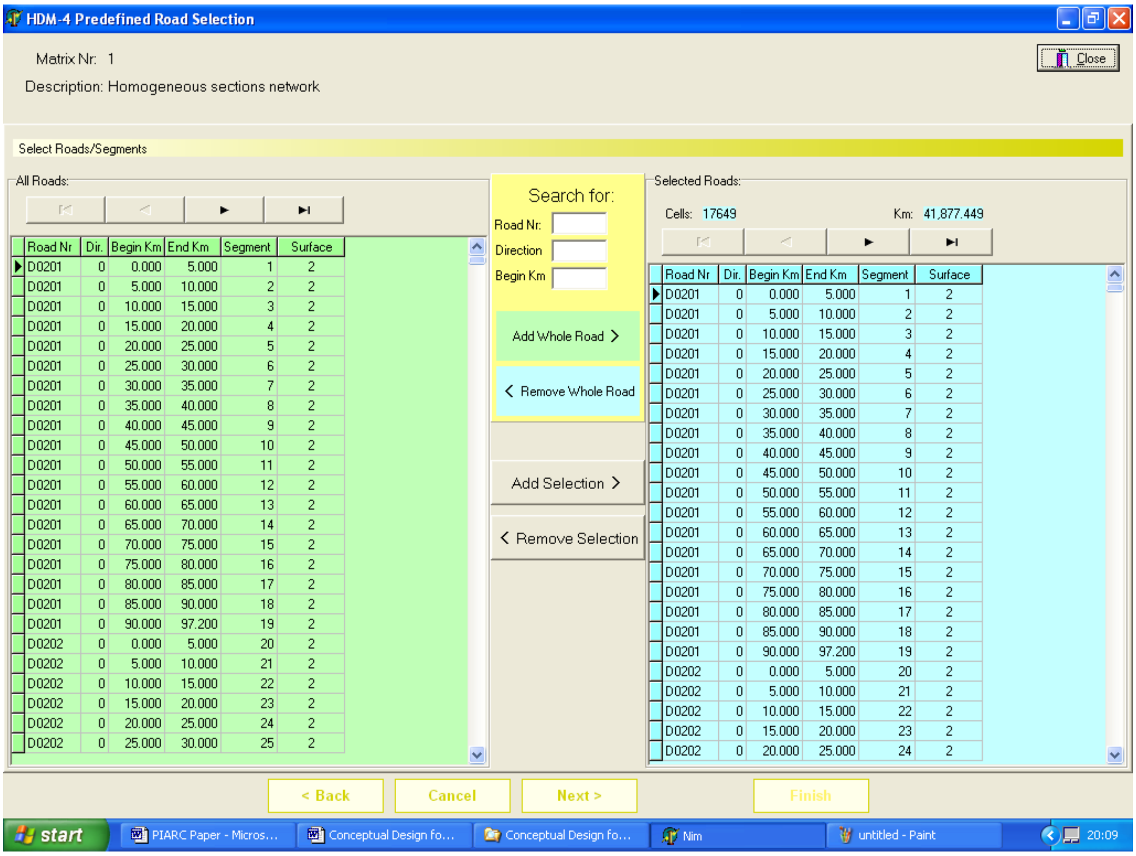


Figure 4. Query form for predefining section selection

In the case of a strategic or network analysis, typically either the entire road network or one or more regions/provinces/states would be selected. The user may also chose to filter out those sections which meet (or fail to meet) certain selection criteria. These might include thresholds for AADT, number of heavy vehicles, roughness, percentage cracking, pavement strength, etc. This facility allows the user to concentrate the analysis on those sections in most need of treatment.

In the case of tactical analyses, the designations of the actual sections to be analysed are typically known. In this case, the user would simply be required to supply the road number, and start and end chainage for each section involved. Alternatively, the user may select the sections to be analysed using the more flexible facilities described above.

Experience of developing similar systems in the past has shown that the process of selecting the road sections to be analysed is often iterative. After conducting an initial query of the RMS database, the user may decide that the resultant set of sections is not quite what he/she requires. Thereafter he/she may wish to delete individual sections from the selection-set, or to run further queries which either replace or supplement the current selection-set.

Once the user is satisfied with the selection-set, the next step in the transfer process is the conversion of the selected road sections into homogeneous segments based on the selected attributes and categories.

2.3 Dynamic Segmentation

HDM-4 requires that all road data must be supplied in the form of homogeneous sections (or segments). A homogeneous section is defined as a length of road for which all attributes (e.g. pavement width, traffic, condition, etc.) are constant for its entire length. Before the selected RMS segments can be analysed in HDM-4, they are converted into homogeneous sections.

The data in the RMS database is not stored as a single set of homogenous sections. The segment lengths for the various data streams (condition, drainage, inventory, structure, traffic, and works history) are not always synchronized. Therefore a segmentation routine has been developed which generates a single set of harmonised homogeneous segments by analysing the various streams of data simultaneously, and identifying road lengths for which all road characteristics are constant.

The dynamic segmentation method has been preferred over the fixed links approach because the latter aggregates data over arbitrary link lengths, even if the interval is not the best for the data items being measured. Dynamic segmentation avoids this short-coming by creating links based on the condition of the pavement (or any other parameter e.g. traffic). This leads to a much more realistic representation of the network since the treatments one applies will be based on the pavement condition.

Dynamic sectioning is achieved by defining the band values for each attribute (for example good roughness < 3 IRI; poor roughness ≥ 3 IRI). The condition data are then analysed and when the condition value changes from one band to another a new section is created.

As shown in Figure 1, the next step in the data transfer process will depend upon the mode of analysis required by the user. In the case of a tactical project-level analysis (project analysis), or for the generation of an annual works programme (tactical-network analysis), the next step will be the creation of 'Homogeneous Sections'. In the case of a strategic level analysis (strategy analysis), the next step will be matrix generation.

2.4 Road Network Matrix Generation

In the case where the user has selected to perform a strategic analysis, which is usually the first step in a sound road management cycle, the generation of a road matrix is required. The creation of road network matrix consists of combining the homogeneous segments created above into a matrix of representative sections. In HDM-4, a strategy analysis is not performed on "real" road sections, but instead on a matrix of representative road sections. Each of the representative sections in the matrix represents a large number of real sections (often thousands of kilometers of road) scattered around the road network, each of which has similar characteristics (e.g. road class, pavement type, traffic, condition, construction quality, etc…). Instead of each of the constituent sections being analysed separately, just the representative section (whose length is the sum of the constituent sections) is analysed. The advantage of this approach is the fast turn-around that it facilitates the ability to iterate to a preferred solution/strategy relatively quickly.

Using this approach, the representative matrix is first generated from the homogeneous segments created above. The key to this approach is the generation of a matrix, which reflects the composition of the road network as accurately as possible. The method used for generating the matrix in the RMS/HDM-4 interface is illustrated in Figure 5.

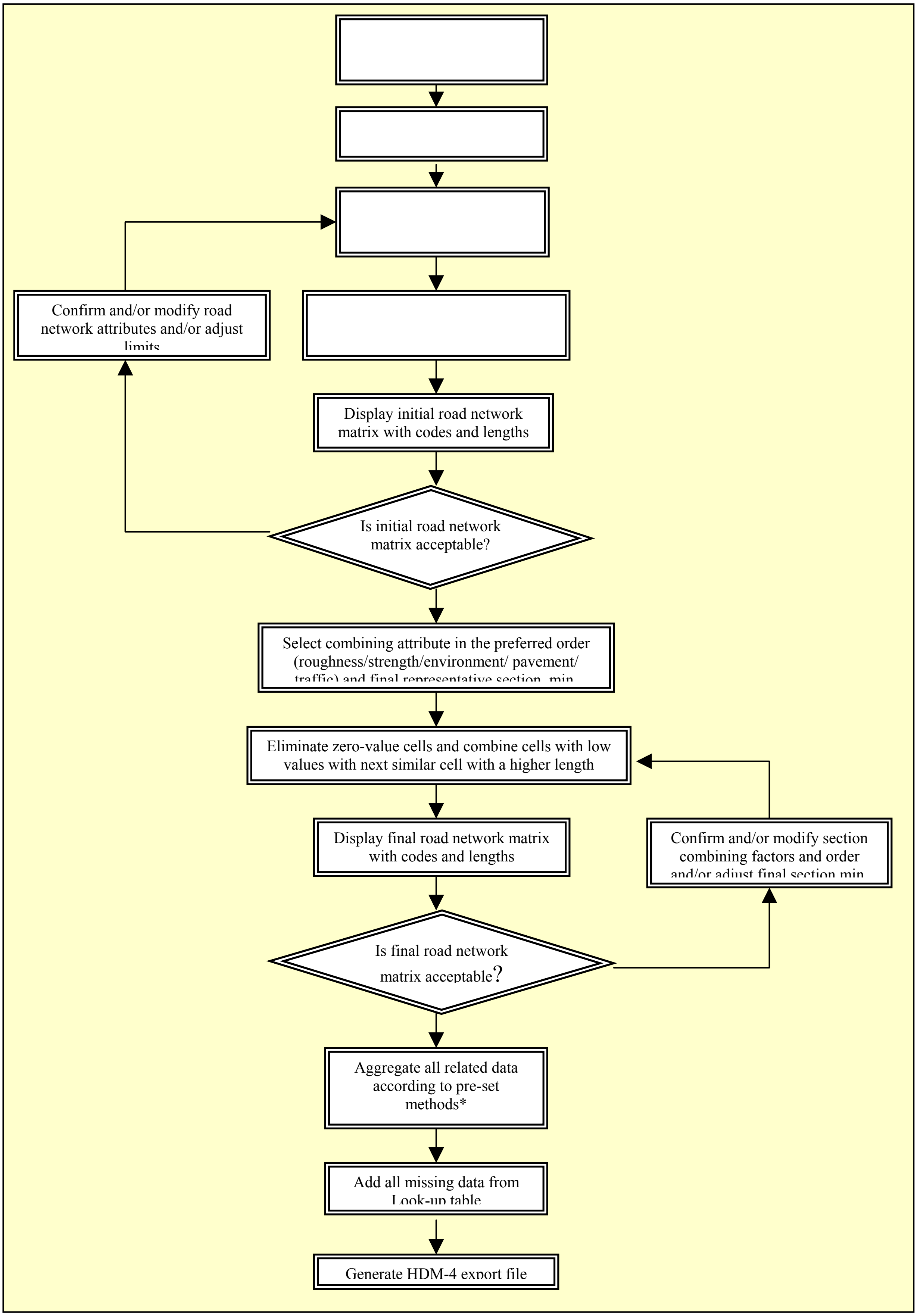
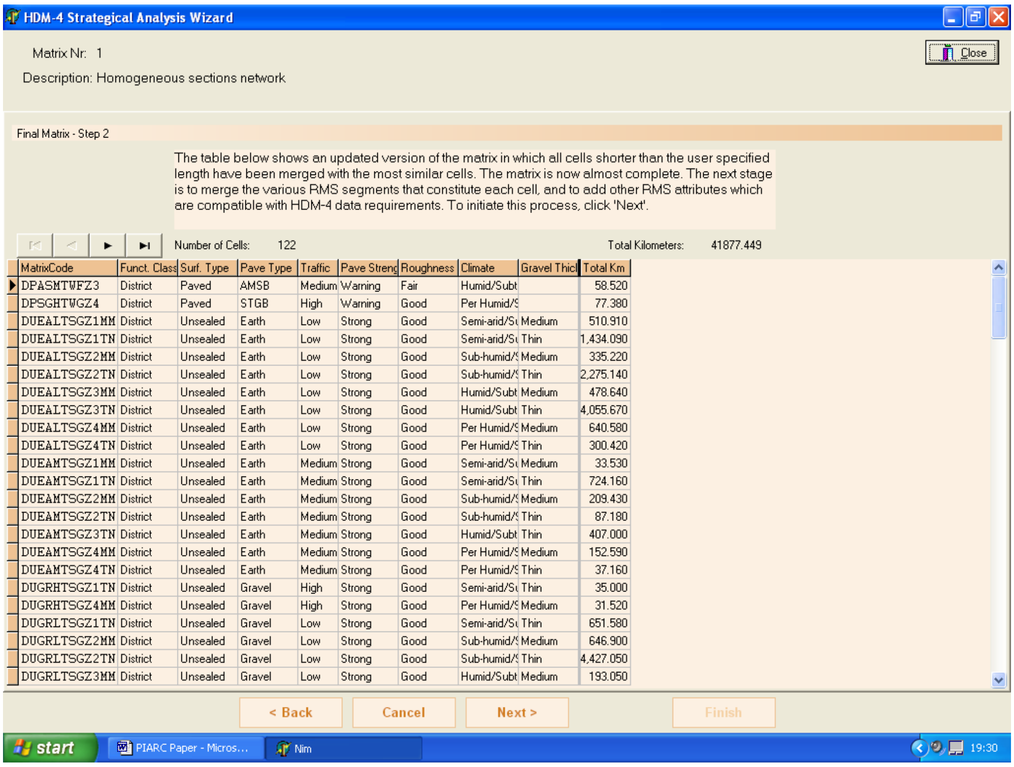


Figure 5: Dynamic Process for the Automatic Generation of a Road Network Matrix

The main problem with matrix generation is that it often results in a large number of relatively short segments. The next stage in the matrix generation process is the merging of short kilometer cells with other similar cells to form cells with a user specified minimum length. For that purpose, the user specifies the required minimum length for the road network matrix. If the Initial Matrix contains any cells which are shorter than the specified minimum length, then these will be combined with cells that have the most similar characteristics using the provided attribute precedence rules which may be configured by the user. This particular facility helps to ensure that the final export set contains no segments which are too short for operational purposes. Figure 6 shows an example of a matrix representing the Namibian road network, consisting of 122 representative sections (down from the initial 170694 standard sections).



MatrixCode	Funct. Class	Surf. Type	Pave Type	Traffic	Pave Streng	Roughness	Climate	Gravel Thicl	Total Km
DPASMTWFZ3	District	Paved	AMSB	Medium	Warning	Fair	Humid/Subt		58.520
DPSGHTWGZ4	District	Paved	STGB	High	Warning	Good	Per Humid/		77.380
DUEALTSGZ1MM	District	Unsealed	Earth	Low	Strong	Good	Semi-arid/S	Medium	510.910
DUEALTSGZ1TN	District	Unsealed	Earth	Low	Strong	Good	Semi-arid/S	Thin	1,434.090
DUEALTSGZ2MM	District	Unsealed	Earth	Low	Strong	Good	Sub-humid/	Medium	335.220
DUEALTSGZ2TN	District	Unsealed	Earth	Low	Strong	Good	Sub-humid/	Thin	2,275.140
DUEALTSGZ3MM	District	Unsealed	Earth	Low	Strong	Good	Humid/Subt	Medium	478.640
DUEALTSGZ3TN	District	Unsealed	Earth	Low	Strong	Good	Humid/Subt	Thin	4,055.670
DUEALTSGZ4MM	District	Unsealed	Earth	Low	Strong	Good	Per Humid/	Medium	640.580
DUEALTSGZ4TN	District	Unsealed	Earth	Low	Strong	Good	Per Humid/	Thin	300.420
DUEAMTSGZ1MM	District	Unsealed	Earth	Medium	Strong	Good	Semi-arid/S	Medium	33.530
DUEAMTSGZ1TN	District	Unsealed	Earth	Medium	Strong	Good	Semi-arid/S	Thin	724.160
DUEAMTSGZ2MM	District	Unsealed	Earth	Medium	Strong	Good	Sub-humid/	Medium	209.430
DUEAMTSGZ2TN	District	Unsealed	Earth	Medium	Strong	Good	Sub-humid/	Thin	87.180
DUEAMTSGZ3TN	District	Unsealed	Earth	Medium	Strong	Good	Humid/Subt	Thin	407.000
DUEAMTSGZ4MM	District	Unsealed	Earth	Medium	Strong	Good	Per Humid/	Medium	152.590
DUEAMTSGZ4TN	District	Unsealed	Earth	Medium	Strong	Good	Per Humid/	Thin	37.160
DUGRHTSGZ1TN	District	Unsealed	Gravel	High	Strong	Good	Semi-arid/S	Thin	35.000
DUGRHTSGZ4MM	District	Unsealed	Gravel	High	Strong	Good	Per Humid/	Medium	31.520
DUGRLTSGZ1TN	District	Unsealed	Gravel	Low	Strong	Good	Semi-arid/S	Thin	651.580
DUGRLTSGZ2MM	District	Unsealed	Gravel	Low	Strong	Good	Sub-humid/	Medium	646.900
DUGRLTSGZ2TN	District	Unsealed	Gravel	Low	Strong	Good	Sub-humid/	Thin	4,427.050
DUGRLTSGZ3MM	District	Unsealed	Gravel	Low	Strong	Good	Humid/Subt	Medium	193.050

Figure 6: Example of Road Network Matrix- Namibian Road Network.

2.5 Homogeneous Sections Generation

In the case where the user has selected to perform a tactical/project analysis, the generation of a network of homogeneous sections is required. The methodology followed is similar to the one described above for road network matrix generation except that for tactical analyses 'real' sections are created by merging together adjacent segments with similar characteristics to form lengths of roads which are suited to form manageable contracts.

Prior to the merging operation, the user specifies a minimum length for a homogeneous section. The same precedence rule as used for the road network matrix is used for the merging of adjacent homogenous segments.

2.6 Derivation of Default Values for Missing Data Items

The road network matrix or homogenous sections thus comprise only those parameters from the RMS database. In order for the matrix to be used in HDM-4, default values or 'HDM-4 data' must be derived for those parameters, which are not included in the matrix.

The main problem associated with preparing any road network data for use in HDM-4 is the considerable number of data items that HDM-4 requires for each road section. HDM-4 requires approximately 90 parameters to be specified for each bituminous section, 60 for concrete sections, and 40 for unsealed sections (N.B. concrete roads are not an issue in Namibia). The RMS database (like most other road databases) contains less than 30 of the data items required by HDM-4 for each section. That leaves a deficit of approximately 60 data items for bituminous pavements that are required by HDM-4 but which are not available in the RMS database. Furthermore, many of these 'missing' data items are obscure, HDM-4 specific parameters (e.g. model calibration parameters) for which specific studies have to be undertaken to obtain reasonable values.

In order to produce an HDM-4 compliant data-set, sensible default values have to be used for these missing parameters. The mechanism which is typically used in similar systems for the derivation of values for the missing data-items is the 'look-up table'.

The look-up table is effectively a list of 'representative sections' which encompasses the range of different road section types found on the NRA road network. One way to think of the look-up table is as a matrix containing sections based on the various combinations of various key parameters such as road class, surface class, pavement construction, traffic level, pavement strength, carriageway width, etc. Each row of this matrix is a representative section with values defined both for these key parameters and also for the various HDM-4 specific parameters. Table 1 is an example of what part of a typical look-up table looks like:

Table 1: Illustration of part of a typical look-up table

Road Class	**Surface Class**	**Traffic**	**Pavement Strength**	**Carriageway Width**	**…**	**Rutting Initiation Factor**	**Rutting Progression Factor**
Trunk	Bituminous	High	High	14.5m	…	0.92	1.00
Trunk	Bituminous	Medium	Medium	14.5m	…	0.84	0.92
Trunk	Bituminous	High	High	12m	…	1.03	1.20
Main	Bituminous	High	Medium	14.5m	…	1.01	1.18
Main	Bituminous	High	Medium	12m	…	1.01	1.01
:	:	:	:	:	:	:	:
Main	Bituminous	Medium	Medium	8m	…	0.93	0.97

2.6 Conversion of RMS Data to HDM-4 Units

At this stage of the transfer process, we now have a set of 'candidate' sections, which include values for all the parameters required by HDM-4 for each road section. These values have been derived wherever possible from the RMS database and in all other cases from the lookup table. In the case of those values derived from the RMS database, several are at this stage not in the same units as those used in HDM-4. For example, in the Namibian implementation of RMS, the various forms of cracking are measured by visual inspection and are recorded on a 1 - 5 scale of severity. In HDM-4, 'All cracking' is supplied as a % of carriageway area, and the other modes of cracking are expressed as a percentage of the area of all cracking. Therefore, the RMS values for cracking have to be converted into HDM-4 'units' before the candidate section can be analysed. The same is true for other RMS data items.

The RMS data items that need to be converted prior to use in HDM-4 have been identified, and methods for conversion have been recommended and incorporated into the automatic process. Once the respective data items have been converted into HDM-4 units, the HDM-4 compliant road sections are ready for analysis in HDM-4. The next step in the transfer process is to write these sections to a transfer file so that they may subsequently transferred to HDM-4.

2.7 Creation of Export Files

The penultimate step in the process of transferring RMS data to HDM-4, is the creation of the road network export files required. The following steps are involved:

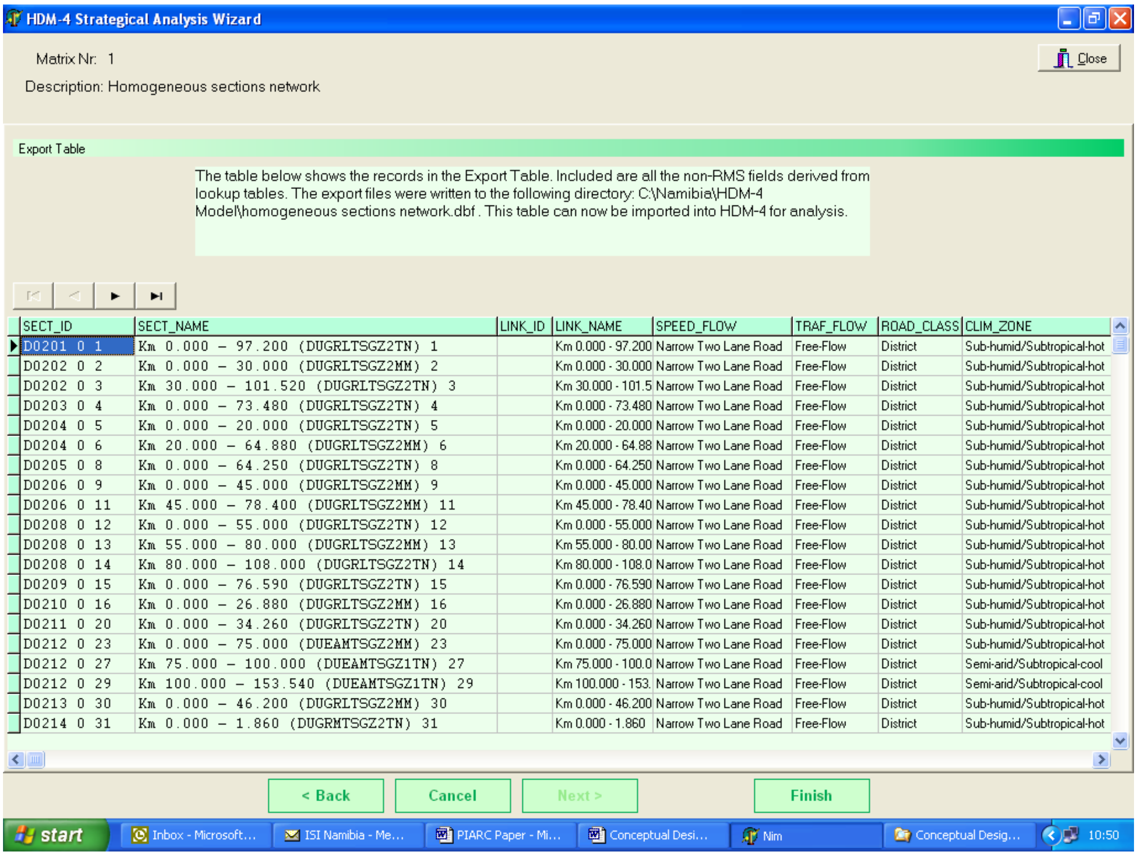
1. Having created the road network to be exported, the user instigates the file creation process. In doing so he specifies a folder into which the export data-set will be written.

2. A copy of the automatically generated road network containing the matrix or the homogeneous sections is written to this folder.

3. The interface program invokes the HDM-4 import function to import the road network into the existing HDM-4 workspace.

At this point, the user selected RMS data has now been transferred to HDM-4 and is ready for analysis. In order to use this data, the user simply has to invoke HDM-4 and open the workspace. The analysis object may then be opened, and the analysis run.

Figure 7 shows an example of the transfer table containing the a network of homogeneous sections for Namibia created using the automatic tool.



SECT_ID	SECT_NAME	LINK_ID	LINK_NAME	SPEED_FLOW	TRAF_FLOW	ROAD_CLASS	CLIM_ZONE
D0201 0 1	Km 0.000 – 97.200 (DUGRLTSGZ2TN) 1		Km 0.000 - 97.200	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot
D0202 0 2	Km 0.000 – 30.000 (DUGRLTSGZ2MM) 2		Km 0.000 - 30.000	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot
D0202 0 3	Km 30.000 – 101.520 (DUGRLTSGZ2TN) 3		Km 30.000 - 101.5	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot
D0203 0 4	Km 0.000 – 73.480 (DUGRLTSGZ2TN) 4		Km 0.000 - 73.480	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot
D0204 0 5	Km 0.000 – 20.000 (DUGRLTSGZ2TN) 5		Km 0.000 - 20.000	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot
D0204 0 6	Km 20.000 – 64.880 (DUGRLTSGZ2MM) 6		Km 20.000 - 64.88	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot
D0205 0 8	Km 0.000 – 64.250 (DUGRLTSGZ2TN) 8		Km 0.000 - 64.250	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot
D0206 0 9	Km 0.000 – 45.000 (DUGRLTSGZ2MM) 9		Km 0.000 - 45.000	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot
D0206 0 11	Km 45.000 – 78.400 (DUGRLTSGZ2MM) 11		Km 45.000 - 78.40	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot
D0208 0 12	Km 0.000 – 55.000 (DUGRLTSGZ2TN) 12		Km 0.000 - 55.000	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot
D0208 0 13	Km 55.000 – 80.000 (DUGRLTSGZ2MM) 13		Km 55.000 - 80.00	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot
D0208 0 14	Km 80.000 – 108.000 (DUGRLTSGZ2TN) 14		Km 80.000 - 108.0	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot
D0209 0 15	Km 0.000 – 76.590 (DUGRLTSGZ2TN) 15		Km 0.000 - 76.590	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot
D0210 0 16	Km 0.000 – 26.880 (DUGRLTSGZ2MM) 16		Km 0.000 - 26.880	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot
D0211 0 20	Km 0.000 – 34.260 (DUGRLTSGZ2TN) 20		Km 0.000 - 34.260	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot
D0212 0 23	Km 0.000 – 75.000 (DUEAMTSGZ2MM) 23		Km 0.000 - 75.000	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot
D0212 0 27	Km 75.000 – 100.000 (DUEAMTSGZ1TN) 27		Km 75.000 - 100.0	Narrow Two Lane Road	Free-Flow	District	Semi-arid/Subtropical-cool
D0212 0 29	Km 100.000 – 153.540 (DUEAMTSGZ1TN) 29		Km 100.000 - 153.	Narrow Two Lane Road	Free-Flow	District	Semi-arid/Subtropical-cool
D0213 0 30	Km 0.000 – 46.200 (DUGRLTSGZ2MM) 30		Km 0.000 - 46.200	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot
D0214 0 31	Km 0.000 – 1.860 (DUGRMTSGZ2TN) 31		Km 0.000 - 1.860	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot

Figure 7: Example of an HDM-4 export table

4. CONCLUSION

This tool has been developed to provide the Namibian Road Authority with an automatic process for transferring data stored in the existing RMS database into HDM-4 in the format required by the latter. The tool minimises the amount of human intervention required in the transfer process, thus reducing the scope for introducing errors, the time required to produce data-sets and consequently the cost of doing so. With this tool, Namibia RA staff are able to produce a representative matrix of a road network that consists of 17694 standard segments in few minutes instead of the usual weeks if not months that it takes to derive it manually.

The described approach is viewed by the HDM-4 team as the best way forward for achieving an efficient and effective integration between existing Pavement Management Systems and the HDM-4 model.

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- Terence Zekveld, Infrastructure System Integrators (ISI)- South Africa.

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Summary

This paper describes the development of automatic processes (based on the dynamic segmentation techniques) to generate road network matrices and homogeneous sections for use in road planning analyses within the Highway Management and Development (HDM-4) model. These processes are used to transfer data stored in the relational Road Management System (RMS) database managed by the Namibian Road Authority in an efficient and effective manner.

In order to simplify the process of performing a strategy analysis for an entire road network, HDM-4 employs the concept of a road network matrix. This matrix consists of a number of representative road sections, which reflect the various types of road which exist in the relevant road network. Each representative section is defined in terms of a number of key attributes that most influence pavement performance and road user costs. For tactical economic analyses, HDM-4 uses the concept of homogeneous sections. These are physical sections of the network for which all road characteristics are constant. The current version of HDM-4 does not include a process that can be used to automatically generate a road network matrix or homogeneous sections, and users are required to do this externally. However, both the creation of a road network matrix, and the conversion of a network into homogenous sections are often cumbersome, particularly when the source network consists of thousands of kilometres of road sections.

Amongst other benefits, this automatic data transfer tool has enabled the Roads Authority staff to produce a representative matrix for strategic planning analysis of a road network that consists of 17,694 basic segments in a few minutes, instead of the usual weeks if not months that it takes to derive it manually. This tool does not only provide the Road Authority in Namibia with a flexible tool that can assist them in the definition of their road network maintenance programmes, but it also significantly reduces the amount of time used for data preparation and analysis and consequently cost.

This is approach is viewed the best way forward for achieving an efficient and effective integration between existing Pavement Management Systems and the HDM-4 model.

KEY WORDS: AUTOMATIC / ROAD / SECTION / NETWORK / MATRIX / HOMOGENEOUS.

1. INTRODUCTION

This paper describes the development of the data transfer tool encapsulating the automatic processes for generating road matrices and homogeneous sections for use in the Highway Development and Management (HDM-4) model. This work was carried out as part of the overall integration project aimed at linking HDM-4 with the existing Namibian Road Management System (RMS) via a Network Integration Module (NIM). The NIM system provides the overall framework for the management of the Namibian national road network. Senior policy makers and road managers within the Namibian Roads Authority require relevant and up to date information in order to analyse and to justify longer-term strategies. These automatic processes provide the overall RMS system with the capability to link up with HDM-4 in a quick and effective manner hence supporting such needs in an efficient mode.

These processes are part of a global integration tool that includes data import from the RMS to HDM-4 as well as export of analyses results from HDM-4 back to the RMS system as Figure 1 shows. Only the first part of the integration is discussed in this paper.

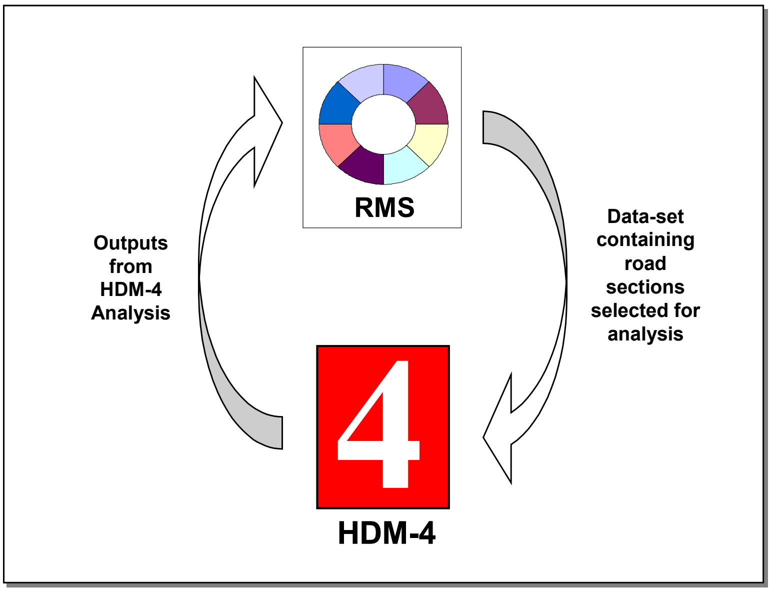


Figure 1- Data-Flow between RMS and HDM-4

HDM-4, is the successor to the World Bank Highway Design and Maintenance Standards Model (HDM-III). The new HDM-4 is a powerful system for the analysis of road management and investment alternatives. It incorporates three dedicated applications tools for project level analysis, roadwork programming under constrained budgets, and for strategic planning of long-term network performance and expenditure needs. It is designed to be used as a decision-support tool within a road management system hence its integration within the Namibian system for use at network level.

However, experience has shown that preparing data for HDM-4 for network analyses is not straightforward and could take weeks if not months to get the information in the format required by the model. The main reason for this is that HDM-4 has very particular data input requirements. The main problems involved in transferring road network data from existing databases into HDM-4 are that the latter applies the concepts of a road network matrix (for strategic analyses) and homogeneous sections (for tactical analyses).

Both road matrix elements and homogeneous sections comprise categories of the road network defined according to the key attributes that most influence pavement performance and road user costs. Although it is possible to model basic individual road sections in a strategic or tactical analysis application, it is cumbersome to individually model each road segment as a network may include thousands of kilometres of roads. In the case of Namibia, the entire road network consists of 17694 standard segments of 500 meters each.

Generally, a sophisticated piece of software is required to fulfil these requirements, and to establish a sustainable link between HDM-4 and the road database. The following sections describe the various steps involved in the development of this tool that manages the automatic generation of road network matrices and homogeneous sections for network analyses. Figure 2 gives an overview of the phases involved in the automatic generation of these HDM-4 data-sets.

The above tool is implemented as part of the Namibian Network Integration Module (NIM) between HDM-4 and the RMS database and is used as the main data preparation system for network maintenance planning. The NIM user interface is implemented as a step-by-step wizard that guides the user in the preparation of the HDM-4 network data.

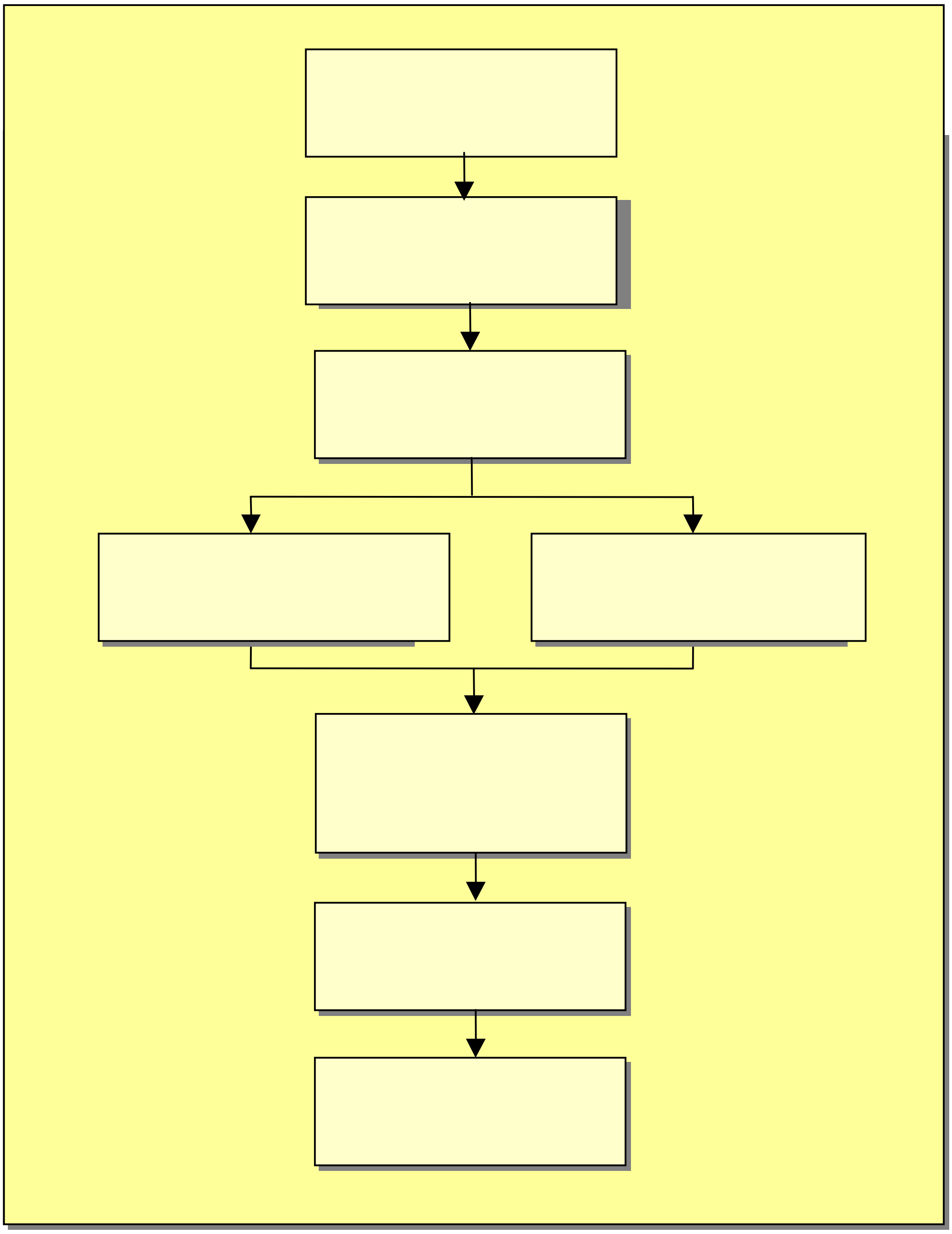


Figure 2 - Overview of the automatic generation of HDM-4 data-sets

2. DESCRIPTION OF THE AUTOMATIC GENERATION PROCESS

2.1 Definition of Attributes that most influence performance and RUCs.

The first step in the process of generating the HDM-4 input data is the selection of those attributes that most influence pavement performance or road user cost. This is done through a free-form query (see Figure 3) with a list of up to 22 attributes for both paved and unsealed roads. For each attribute, the user defines the various categories of allowable values and their value bands (e.g. traffic, strength, condition, etc…). The user may change or modify those attributes at any time during the automatic generation process.

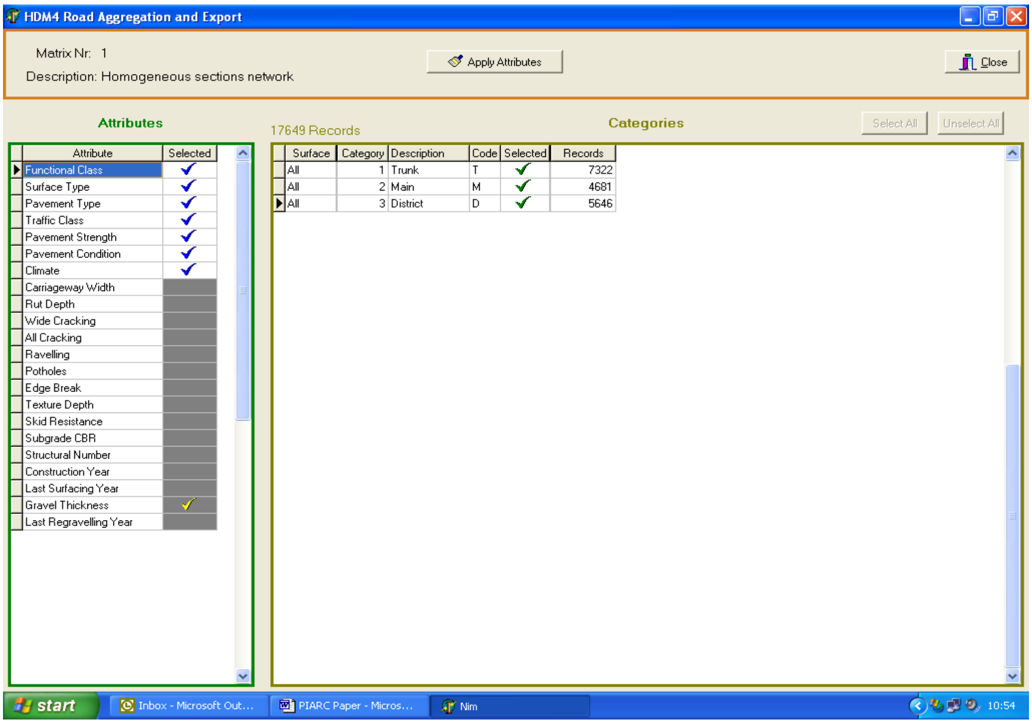


Figure 3: Freeform query for selecting pavement attributes

With the above wizard, the user is able to select from the following attributes and predefine the attribute categories and associated value bands:

- Functional Class (Trunk; Main; District)
- Surface Type (Bituminous; Unsealed)
- Pavement Type (e.g. Asphalt Mix on Asphalt Base (AMAB); etc..)
- Traffic Class (e.g. High; Medium; Low)
- Pavement Strength- Deflection (e.g. Strong; Acceptable; Warning)
- Pavement Condition (e.g. Good; Fair; Poor)
- Climate (e.g. Semi-arid; Sub-humid; Humid; Per-humid)
- Carriageway Width (e.g. Standard; Narrow)
- Rut Depth (e.g. Good; Fair; Poor)
- All Cracking (e.g. Good; Fair; Poor)
- Wide Cracking (e.g. Good; Fair; Poor)
- Ravelling (e.g. Good; Fair; Poor)
- Potholes (e.g. Good; Fair; Poor)
- Edge Break (e.g. Good; Fair; Poor)
- Texture Depth (Coarse; Medium; Fine)
- Skid Resistance (e.g. Good; Fair; Poor)
- Subgrade CBR (e.g. Good; Fair; Poor)
- Structural Number (e.g. Strong; Acceptable; Warning)
- Construction Year (Young; Medium; Old)
- Last Surfacing Year (Young; Medium; Old)
- Gravel Thickness (Thin; Medium; Thick)
- Last Regravelling Year (Young; Old)

The principal “rule-of-thumb” when selecting which attributes to be used, is that the more attributes selected, the finer the subsequent analysis will be. However, in deciding the number attributes to be used, the user should bear-in-mind that more attributes will increase the matrix size or the number of homogeneous sections and consequently slow-down the analysis and makes results exploitation more cumbersome.

2.2 Selection of Sections to be Analysed in HDM-4

The second step in the process of generating HDM-4 data-sets is the user selection of the road sections that he/she wishes to analyse in HDM-4. This choice will depend largely upon the type of analysis to be performed and it is done using the Predefined Sets wizard (see Figure 4).

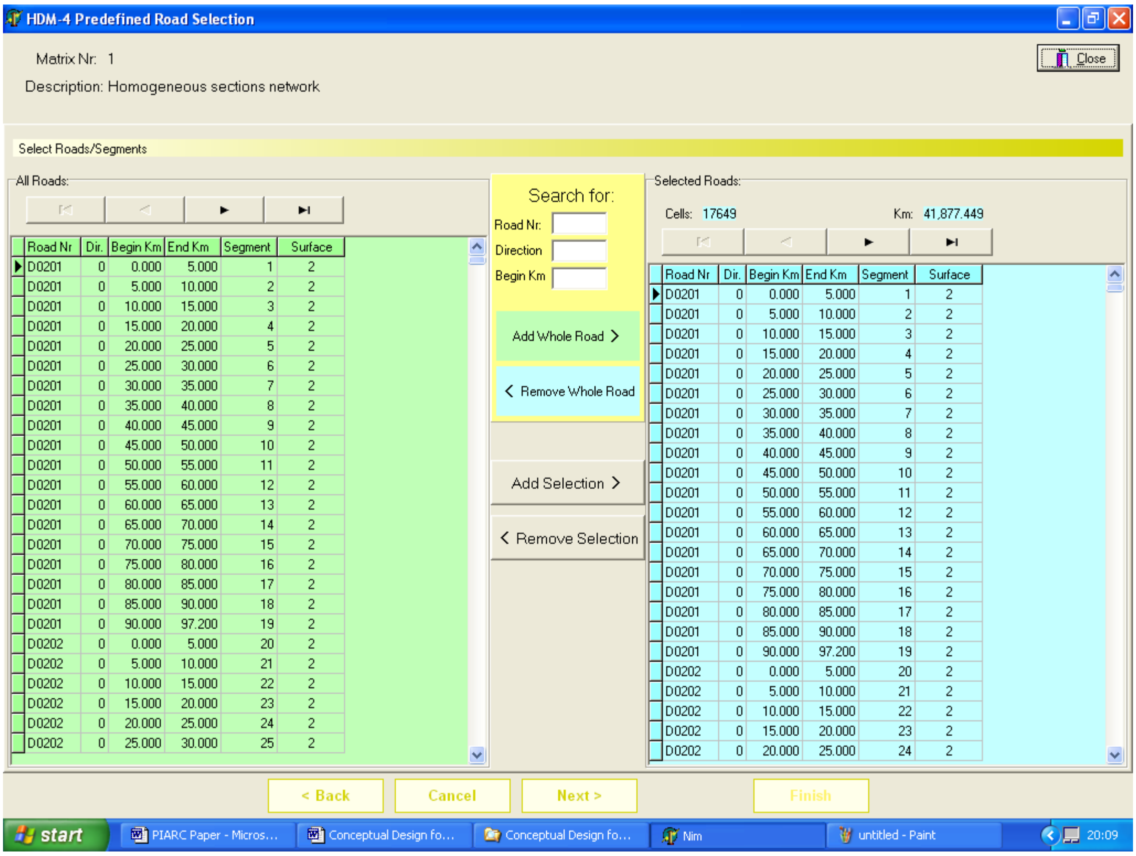


Figure 4. Query form for predefining section selection

In the case of a strategic or network analysis, typically either the entire road network or one or more regions/provinces/states would be selected. The user may also chose to filter out those sections which meet (or fail to meet) certain selection criteria. These might include thresholds for AADT, number of heavy vehicles, roughness, percentage cracking, pavement strength, etc. This facility allows the user to concentrate the analysis on those sections in most need of treatment.

In the case of tactical analyses, the designations of the actual sections to be analysed are typically known. In this case, the user would simply be required to supply the road number, and start and end chainage for each section involved. Alternatively, the user may select the sections to be analysed using the more flexible facilities described above.

Experience of developing similar systems in the past has shown that the process of selecting the road sections to be analysed is often iterative. After conducting an initial query of the RMS database, the user may decide that the resultant set of sections is not quite what he/she requires. Thereafter he/she may wish to delete individual sections from the selection-set, or to run further queries which either replace or supplement the current selection-set.

Once the user is satisfied with the selection-set, the next step in the transfer process is the conversion of the selected road sections into homogeneous segments based on the selected attributes and categories.

2.3 Dynamic Segmentation

HDM-4 requires that all road data must be supplied in the form of homogeneous sections (or segments). A homogeneous section is defined as a length of road for which all attributes (e.g. pavement width, traffic, condition, etc.) are constant for its entire length. Before the selected RMS segments can be analysed in HDM-4, they are converted into homogeneous sections.

The data in the RMS database is not stored as a single set of homogenous sections. The segment lengths for the various data streams (condition, drainage, inventory, structure, traffic, and works history) are not always synchronized. Therefore a segmentation routine has been developed which generates a single set of harmonised homogeneous segments by analysing the various streams of data simultaneously, and identifying road lengths for which all road characteristics are constant.

The dynamic segmentation method has been preferred over the fixed links approach because the latter aggregates data over arbitrary link lengths, even if the interval is not the best for the data items being measured. Dynamic segmentation avoids this short-coming by creating links based on the condition of the pavement (or any other parameter e.g. traffic). This leads to a much more realistic representation of the network since the treatments one applies will be based on the pavement condition.

Dynamic sectioning is achieved by defining the band values for each attribute (for example good roughness < 3 IRI; poor roughness ≥ 3 IRI). The condition data are then analysed and when the condition value changes from one band to another a new section is created.

As shown in Figure 1, the next step in the data transfer process will depend upon the mode of analysis required by the user. In the case of a tactical project-level analysis (project analysis), or for the generation of an annual works programme (tactical-network analysis), the next step will be the creation of ‘Homogeneous Sections’. In the case of a strategic level analysis (strategy analysis), the next step will be matrix generation.

2.4 Road Network Matrix Generation

In the case where the user has selected to perform a strategic analysis, which is usually the first step in a sound road management cycle, the generation of a road matrix is required. The creation of road network matrix consists of combining the homogeneous segments created above into a matrix of representative sections. In HDM-4, a strategy analysis is not performed on “real” road sections, but instead on a matrix of representative road sections. Each of the representative sections in the matrix represents a large number of real sections (often thousands of kilometers of road) scattered around the road network, each of which has similar characteristics (e.g. road class, pavement type, traffic, condition, construction quality, etc…). Instead of each of the constituent sections being analysed separately, just the representative section (whose length is the sum of the constituent sections) is analysed. The advantage of this approach is the fast turn-around that it facilitates the ability to iterate to a preferred solution/strategy relatively quickly.

Using this approach, the representative matrix is first generated from the homogeneous segments created above. The key to this approach is the generation of a matrix, which reflects the composition of the road network as accurately as possible. The method used for generating the matrix in the RMS/HDM-4 interface is illustrated in Figure 5.

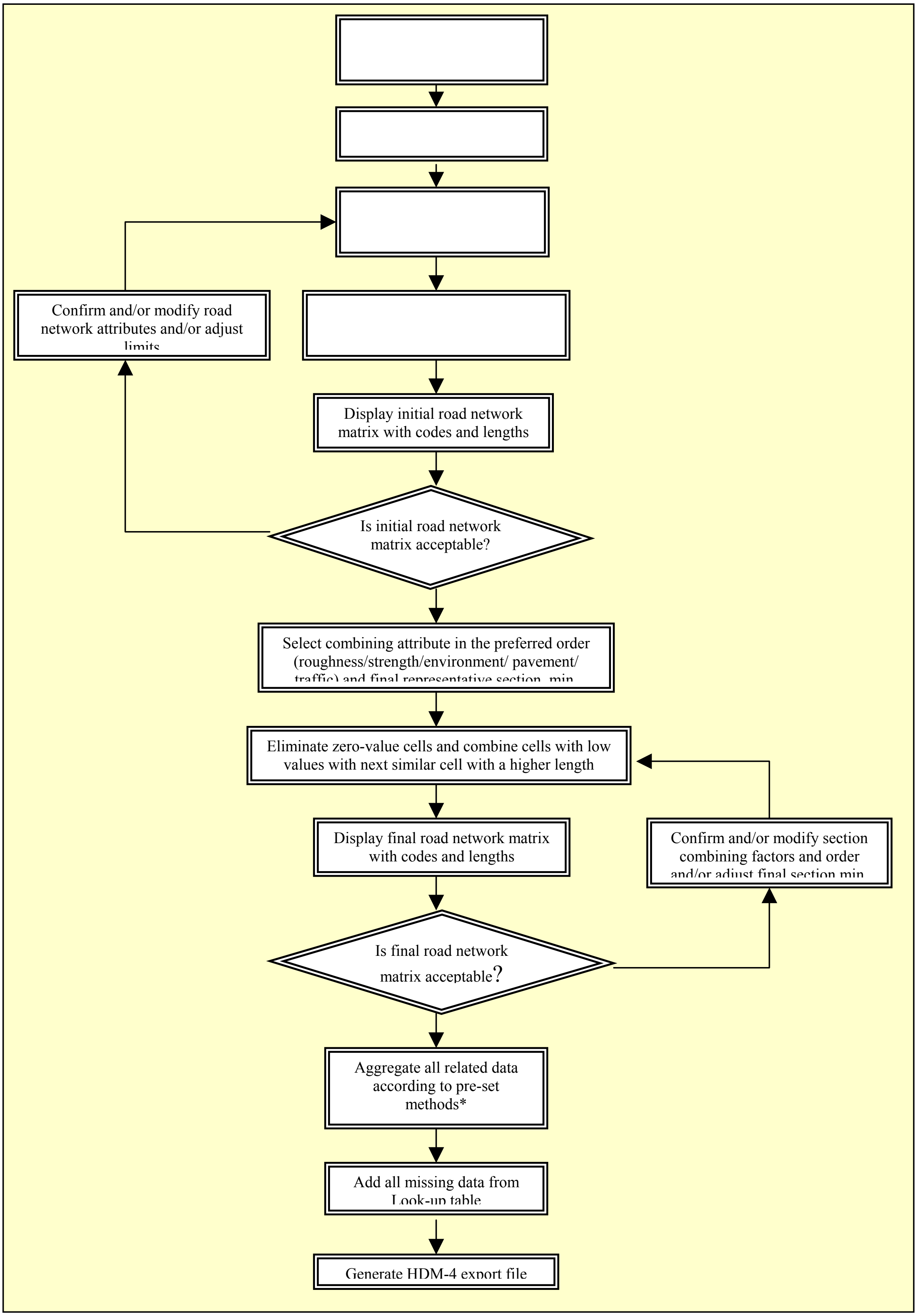


Figure 5: Dynamic Process for the Automatic Generation of a Road Network Matrix

The main problem with matrix generation is that it often results in a large number of relatively short segments. The next stage in the matrix generation process is the merging of short kilometer cells with other similar cells to form cells with a user specified minimum length. For that purpose, the user specifies the required minimum length for the road network matrix. If the Initial Matrix contains any cells which are shorter than the specified minimum length, then these will be combined with cells that have the most similar characteristics using the provided attribute precedence rules which may be configured by the user. This particular facility helps to ensure that the final export set contains no segments which are too short for operational purposes. Figure 6 shows an example of a matrix representing the Namibian road network, consisting of 122 representative sections (down from the initial 170694 standard sections).

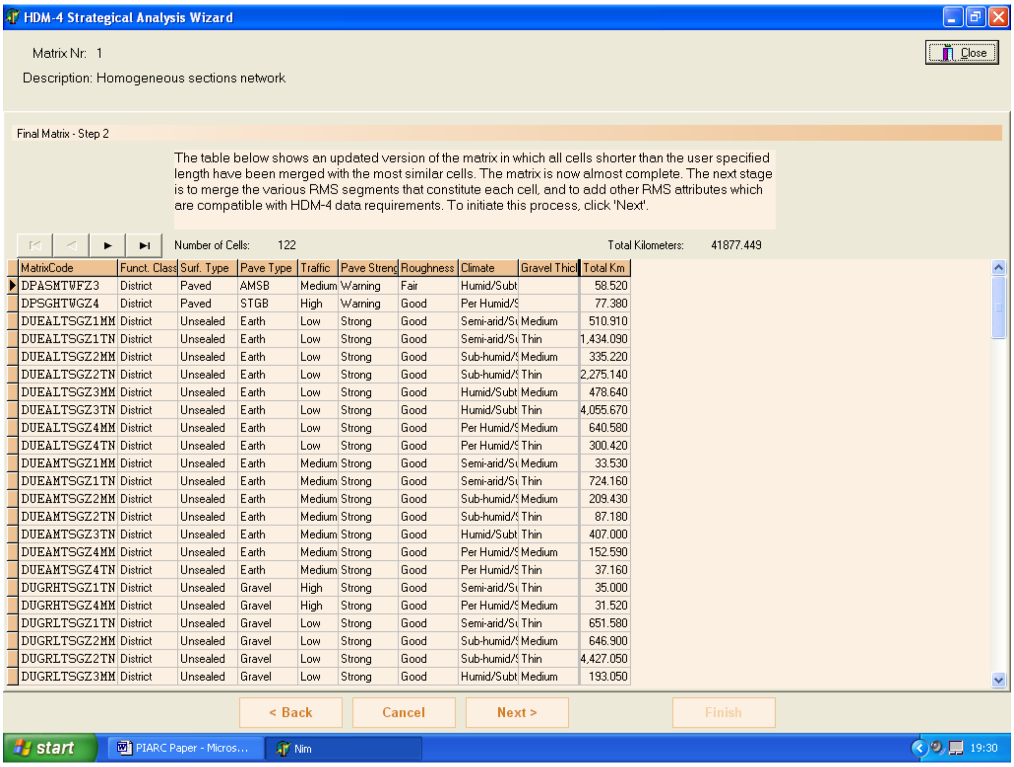


Figure 6: Example of Road Network Matrix- Namibian Road Network.

2.5 Homogeneous Sections Generation

In the case where the user has selected to perform a tactical/project analysis, the generation of a network of homogeneous sections is required. The methodology followed is similar to the one described above for road network matrix generation except that for tactical analyses 'real' sections are created by merging together adjacent segments with similar characteristics to form lengths of roads which are suited to form manageable contracts.

Prior to the merging operation, the user specifies a minimum length for a homogeneous section. The same precedence rule as used for the road network matrix is used for the merging of adjacent homogenous segments.

2.6 Derivation of Default Values for Missing Data Items

The road network matrix or homogenous sections thus comprise only those parameters from the RMS database. In order for the matrix to be used in HDM-4, default values or 'HDM-4 data' must be derived for those parameters, which are not included in the matrix.

The main problem associated with preparing any road network data for use in HDM-4 is the considerable number of data items that HDM-4 requires for each road section. HDM-4 requires approximately 90 parameters to be specified for each bituminous section, 60 for concrete sections, and 40 for unsealed sections (N.B. concrete roads are not an issue in Namibia). The RMS database (like most other road databases) contains less than 30 of the data items required by HDM-4 for each section. That leaves a deficit of approximately 60 data items for bituminous pavements that are required by HDM-4 but which are not available in the RMS database. Furthermore, many of these 'missing' data items are obscure, HDM-4 specific parameters (e.g. model calibration parameters) for which specific studies have to be undertaken to obtain reasonable values.

In order to produce an HDM-4 compliant data-set, sensible default values have to be used for these missing parameters. The mechanism which is typically used in similar systems for the derivation of values for the missing data-items is the 'look-up table'.

The look-up table is effectively a list of 'representative sections' which encompasses the range of different road section types found on the NRA road network. One way to think of the look-up table is as a matrix containing sections based on the various combinations of various key parameters such as road class, surface class, pavement construction, traffic level, pavement strength, carriageway width, etc. Each row of this matrix is a representative section with values defined both for these key parameters and also for the various HDM-4 specific parameters. Table 1 is an example of what part of a typical look-up table looks like:

Table 1: Illustration of part of a typical look-up table

Road Class	Surface Class	Traffic	Pavement Strength	Carriageway Width	…	Rutting Initiation Factor	Rutting Progression Factor
Trunk	Bituminous	High	High	14.5m	…	0.92	1.00
Trunk	Bituminous	Medium	Medium	14.5m	…	0.84	0.92
Trunk	Bituminous	High	High	12m	…	1.03	1.20
Main	Bituminous	High	Medium	14.5m	…	1.01	1.18
Main	Bituminous	High	Medium	12m	…	1.01	1.01
:	:	:	:	:	:	:	:
Main	Bituminous	Medium	Medium	8m	…	0.93	0.97

2.6 Conversion of RMS Data to HDM-4 Units

At this stage of the transfer process, we now have a set of 'candidate' sections, which include values for all the parameters required by HDM-4 for each road section. These values have been derived wherever possible from the RMS database and in all other cases from the lookup table. In the case of those values derived from the RMS database, several are at this stage not in the same units as those used in HDM-4. For example, in the Namibian implementation of RMS, the various forms of cracking are measured by visual inspection and are recorded on a 1 - 5 scale of severity. In HDM-4, 'All cracking' is supplied as a % of carriageway area, and the other modes of cracking are expressed as a percentage of the area of all cracking. Therefore, the RMS values for cracking have to be converted into HDM-4 'units' before the candidate section can be analysed. The same is true for other RMS data items.

The RMS data items that need to be converted prior to use in HDM-4 have been identified, and methods for conversion have been recommended and incorporated into the automatic process. Once the respective data items have been converted into HDM-4 units, the HDM-4 compliant road sections are ready for analysis in HDM-4. The next step in the transfer process is to write these sections to a transfer file so that they may subsequently transferred to HDM-4.

2.7 Creation of Export Files

The penultimate step in the process of transferring RMS data to HDM-4, is the creation of the road network export files required. The following steps are involved:

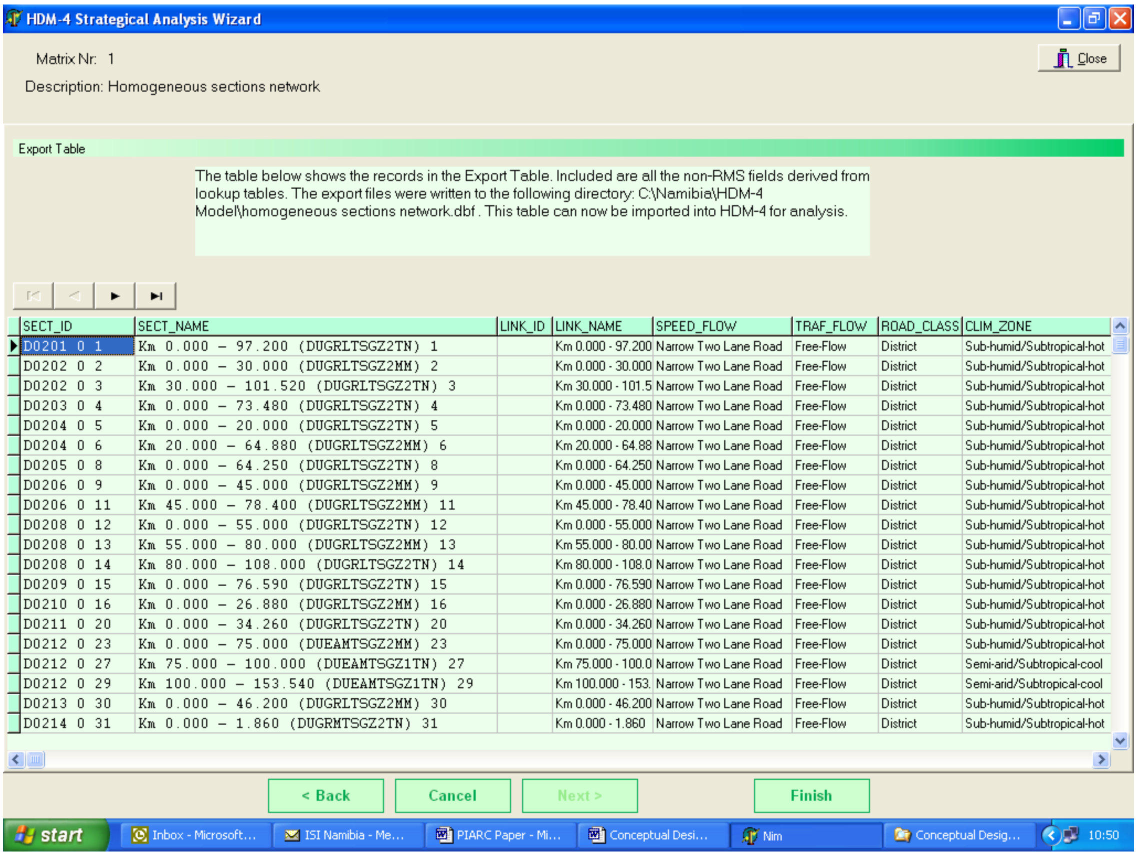
5. Having created the road network to be exported, the user instigates the file creation process. In doing so he specifies a folder into which the export data-set will be written.

6. A copy of the automatically generated road network containing the matrix or the homogeneous sections is written to this folder.

7. The interface program invokes the HDM-4 import function to import the road network into the existing HDM-4 workspace.

At this point, the user selected RMS data has now been transferred to HDM-4 and is ready for analysis. In order to use this data, the user simply has to invoke HDM-4 and open the workspace. The analysis object may then be opened, and the analysis run.

Figure 7 shows an example of the transfer table containing the a network of homogeneous sections for Namibia created using the automatic tool.



SECT_ID	SECT_NAME	LINK_ID	LINK_NAME	SPEED_FLOW	TRAF_FLOW	ROAD_CLASS	CLIM_ZONE
D0201 0 1	Km 0.000 – 97.200 (DUGRLTSGZ2TN) 1		Km 0.000 - 97.200	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot
D0202 0 2	Km 0.000 – 30.000 (DUGRLTSGZ2MM) 2		Km 0.000 - 30.000	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot
D0202 0 3	Km 30.000 – 101.520 (DUGRLTSGZ2TN) 3		Km 30.000 - 101.5	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot
D0203 0 4	Km 0.000 – 73.480 (DUGRLTSGZ2TN) 4		Km 0.000 - 73.480	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot
D0204 0 5	Km 0.000 – 20.000 (DUGRLTSGZ2TN) 5		Km 0.000 - 20.000	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot
D0204 0 6	Km 20.000 – 64.880 (DUGRLTSGZ2MM) 6		Km 20.000 - 64.88	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot
D0205 0 8	Km 0.000 – 64.250 (DUGRLTSGZ2TN) 8		Km 0.000 - 64.250	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot
D0206 0 9	Km 0.000 – 45.000 (DUGRLTSGZ2MM) 9		Km 0.000 - 45.000	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot
D0206 0 11	Km 45.000 – 78.400 (DUGRLTSGZ2MM) 11		Km 45.000 - 78.40	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot
D0208 0 12	Km 0.000 – 55.000 (DUGRLTSGZ2TN) 12		Km 0.000 - 55.000	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot
D0208 0 13	Km 55.000 – 80.000 (DUGRLTSGZ2MM) 13		Km 55.000 - 80.00	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot
D0208 0 14	Km 80.000 – 108.000 (DUGRLTSGZ2TN) 14		Km 80.000 - 108.0	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot
D0209 0 15	Km 0.000 – 76.590 (DUGRLTSGZ2TN) 15		Km 0.000 - 76.590	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot
D0210 0 16	Km 0.000 – 26.880 (DUGRLTSGZ2MM) 16		Km 0.000 - 26.880	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot
D0211 0 20	Km 0.000 – 34.260 (DUGRLTSGZ2TN) 20		Km 0.000 - 34.260	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot
D0212 0 23	Km 0.000 – 75.000 (DUEAMTSGZ2MM) 23		Km 0.000 - 75.000	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot
D0212 0 27	Km 75.000 – 100.000 (DUEAMTSGZ1TN) 27		Km 75.000 - 100.0	Narrow Two Lane Road	Free-Flow	District	Semi-arid/Subtropical-cool
D0212 0 29	Km 100.000 – 153.540 (DUEAMTSGZ1TN) 29		Km 100.000 - 153.	Narrow Two Lane Road	Free-Flow	District	Semi-arid/Subtropical-cool
D0213 0 30	Km 0.000 – 46.200 (DUGRLTSGZ2MM) 30		Km 0.000 - 46.200	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot
D0214 0 31	Km 0.000 – 1.860 (DUGRMTSGZ2TN) 31		Km 0.000 - 1.860	Narrow Two Lane Road	Free-Flow	District	Sub-humid/Subtropical-hot

Figure 7: Example of an HDM-4 export table

8. CONCLUSION

This tool has been developed to provide the Namibian Road Authority with an automatic process for transferring data stored in the existing RMS database into HDM-4 in the format required by the latter. The tool minimises the amount of human intervention required in the transfer process, thus reducing the scope for introducing errors, the time required to produce data-sets and consequently the cost of doing so. With this tool, Namibia RA staff are able to produce a representative matrix of a road network that consists of 17694 standard segments in few minutes instead of the usual weeks if not months that it takes to derive it manually.

The described approach is viewed by the HDM-4 team as the best way forward for achieving an efficient and effective integration between existing Pavement Management Systems and the HDM-4 model.

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- Terence Zekveld, Infrastructure System Integrators (ISI)- South Africa.

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