Title : Case Study - Complete Customer Usage Profiling Example Raw Data through Track Correlation to Accelerated Rig Drive In '4' Days.

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Abstract :

Many automotive companies need to design vehicles using load cases and data that represent 'realistic customer targets'. During 1999 Iveco worked with nCode in a Technology Transfer Project to develop an understanding of their Australian Target Usage Pattern. This was successful, but once a target usage is known there still remains the necessity to convert this to real data to be used by the Design & Development functions.

This paper illustrates how the target mixture of road surfaces and available test tracks were mapped to produce accelerated track based equivalents, and appropriate test rig drive signals.

The initial road load data for such an exercise is extremely large; all road surface types; and every test track. Factor this by the number of vehicle load conditions (GVW, half & kerb), 28 plus measurements, 500 samples per sec etc. It can be seen that the quantity of data to be handled requires careful planning & management.

State of the art Anomaly Checking and automatic verification techniques were used, as was careful planning within a series of automated procedures allowed the data to be verified and analysed mostly overnight.

Pre-planning using a structured Data management System also ensured that any data was never duplicated, ambiguous or lost. It has been noted that most errors arise due to lack of knowledge of the history of the data rather than problems with the data itself.

These automated procedures also provided initial load case conditions for CAE processes, with the added advantage that they are known to be equivalent to a realistic customer usage target.

Subsequently, the track mixture data was also reduced, using fatigue-editing methods, to provide full multi-axial rig drive signals.

This was achieved in a 4-day period, including training and essential confirmation exercises.

Biographies

Giuseppe Mainieri
(Test Manager - Iveco Truck)

Giuseppe Mainieri studied Electronic Engineering & received his Degree in 1994.

He has worked in IVECO since 1995 where at first he was involved in vehicle road data acquisition and analysis with particular attention to vibration and related fatigue aspects.

Since 1999 he is in charge of the Stress Analysis & NVH testing department where he is focusing on the development of new data analysis techniques for accelerated vehicle testing methods.

David Ensor BSc (Hon's) CEng MIMechE
(Global Application Engineering Manager - nCode International)

David Ensor studied Mechanical Engineering & received his Honours Degree in 1977.

He has worked at GKN on transmissions, where he managed a new test laboratory, then for various parts of Rover Group & Leyland Vans as Manager of Instrumentation & Data Analysis, and he was Manager of the Advanced Technology facility at DAF Vans.

He developed Customer Usage Profiling techniques for design load cases, & NVH these techniques were applied to vehicle life target & endurance specifications.

His speciality is in measurement & analysis methods, instrumentation design, data acquisition, test rig and vehicle testing methods.

He joined nCode in 1993, following a 20-year career in Engineering Development. He is currently Global Application Engineering Manager.

Introduction

Iveco Truck & nCode have been working for some time to establish a series of test and sign off standards based on the experience of nCode personnel in Customer Usage Profiling and using the in-house expertise in Iveco for data collection and rig test.

nCode & Iveco had already performed a large Customer Usage Profiling exercise to assist Iveco to determine the target usage patterns for proving test work for a new market in Australia. The general process has been described in previous papers, and will not be described in detail here. The results of the exercise determined a 95%ile customer usage pattern essentially from market survey and other sales & service statistics interrogated during this early project. Following this it still remained to collect representative road route data, and proving ground data and perform correlation analyses to establish a mixture of track surfaces & events to reproduce this target.

This particular case study describes the methods whereby a set of measurements within a certain market area (Australia) have been verified and classified, then assembled into an appropriate target usage, and correlated against a full set track & event data.

Subsequently these results were manipulated to provide rig drive & FEA load cases, and accessed via a data management structure whereby all the data & load cases can be available by all engineering areas into the future.

History

It is now essential for manufacturing industries to have the design & development functions market led. By this it is meant that products should always fit the customer usage adequately, but not to such an extent as to make them 'over engineered' and hence uneconomical or worse, not profitable.

The whole design, development & manufacturing process - from concept to production - is essentially controlled by the length of the proving cycles, rig drive tests or analysis procedures. These, in turn, are derived from the estimates of vehicle usage upon which they are based. A proving test standard would be developed to equate to vehicle life, rig test drive signals represent typical maximum loading events, and analysis load cases taken from 'real world' situations. These data sets, and hence the functions themselves, will be proportional to the overall target usage required - 200,000 kms, 10,000 hours, 'worst case customer' and so on. So, the whole engineering process time-scale is a function of the overall target values selected. In general it is typical that these overall targets are in error due to lack of information as to the real usage patterns being available, or even worse 'custom & practice' extending the test/load case parameter base due to erroneous factors or safety.

It follows therefore that the needs and demands of the customer must be fully considered at all stages of the design process. This must mean that the range of 'customer usage' should be taken into account throughout the design, development and testing processes. By necessity, this will involve measuring and quantifying the customer environment, and mapping this into specifications, load cases, test conditions in the development processes.

The amount of data generated in determining track and environment parameters, and the proliferation of result files, requires very careful data management systems. It will be necessary to discuss how this is achieved.

This paper will concentrate on the methods and processes within the Automotive Engineering field. But, of course, the needs and requirements of any industry will be very similar.

COMMENTS

Firstly, we need to look at how design, development & test procedures have been developed in the past. It may surprise most of us that many of the parameters used to sign off products are heavily based on 'intelligent guesswork', and rely heavily on experience from 'custom & practice'.

Guesswork	Many proving tests in existence (Belgian Block Pave, Kerb Strikes, General Endurance Routes, etc.) have had the distances & number of repeats set from intelligent guesswork by experienced Engineers.
Worst casing	The vast majority of test tracks, and testing parameters have been established using estimation, or measurements of some worst case condition. Belgian Block Pave, Ride & Handling Tracks, Kerbing, Potholes, Off Road Surfaces have all originated in searching for examples of the worst of that kind of input.
Established practice	After a test has been defined, it rapidly becomes a standard, if only from continuous use. Many times, later generations of Engineer have assumed these tests are based on theory, and as more and more data is collected, they become de-facto Standards and can even be defined as such. It must be remembered that these are the well-defined results from an initial guess.
Basic road load data	Some test standards are based on real data. Vehicles are instrumented and data collected from road or other conditions. A test standard is then developed based on these measurements. Rig test work, Max Braking Conditions, XYZ Suspension Load Cases, are all typical examples of these.
Legislature	Some test standards are determined from legal requirements, usually set so that some arbitrary test has to be matched, Crash Worthiness, NVH Drive-By, Operating Control Loads, etc.

Now all of the above are heavily biased towards strength testing, not for the overall life. These worst case, and general tests are all established to ensure the vehicle does not break at maximum load, and that the vehicle matches the general engineering specification.

It can be very sobering in any industry to ask where exactly the standards and testing procedures have been derived. Generally in any industry with which I have been involved, I usually find the vast majority of Proving Tests are based solely on 'custom & practice'.

It is very difficult to guess such useful items as:

Who is the worst case customer?
How long should a vehicle last?
What mix of road conditions constitutes normal?
What long-term test represents life?
Which customer should test work are based upon?

But it is only by asking and answering these questions that a true Proving and Design requirement be set.

Request

During 1999 nCode was consulted by Iveco to help establish what overall target usage should be used within a new Camper Van market segment in Australia. This process, as described in the previous section, was completed using all of the advanced methods of customer usage profiling. This resulted in an overall 95%ile usage pattern, and mixtures of road surface types and load conditions for Australia. This 95%ile usage then became the target to be aimed for with the accelerated proving test cycle.

It was then decided to continue this project to provide a mixed usage track test equivalent and other load case requirements. So, Iveco set about collecting a set of representative road load data on Australian roads and test track surfaces. This data could then be used to provide multiple input, and multi-dimensional loading correlated to the exact 95%ile customer usage.

It will not be the intention to illustrate the results of the 95%ile usage patterns as these have a great deal of customer confidential information contained within them, both for Iveco in terms of the design & market parameter, and nCode & the author for the methods and processes used. This particular project follows this process and describes the handling and efficient manipulation of a large bulk quantity of data in a short time period.

Iveco, took a representative vehicle to Australia for general road load input, note the methods rely on use of 'whole body type inputs' such as wheel force transducers, displacements, speeds, whole body accelerations, steering loads etc. Iveco spent some weeks collecting a great deal of data on all the individual types of road surfaces arising from the 95%ile usage patterns, and also every event, surface and track on the appropriate proving ground.

Following this extensive data collection, Iveco approached nCode to support & provide technology transfer in the manipulation and correlation of the track data to the road route information. Immediately on return from Australia, the data was presented to nCode in the UK as raw, unchecked data files from an Optim Megadac, on a series of CD-Rom's.

It was also interesting to note that Iveco now required a set of load cases and preferably a rig drive profile to satisfy there current testing need, within the following couple of weeks. This was to ensure meeting a sign-off and 'Job One' schedule inside a few months.

Data

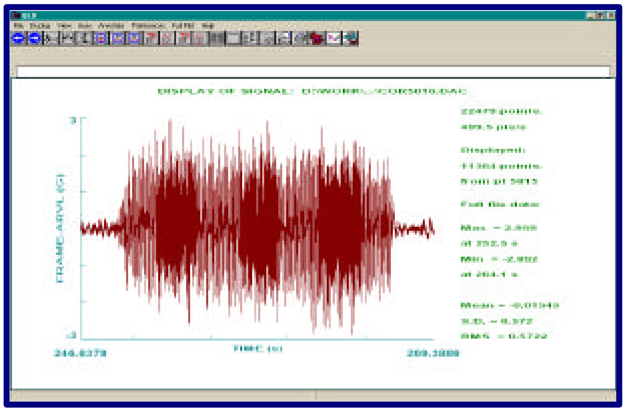
Iveco collected the following raw information:

28 Load Measurements
12 micro Strain
2 Weight conditions
500 samples per sec

16 Test Track Surfaces = 1280 signals ~ approx. 1.5 GByte

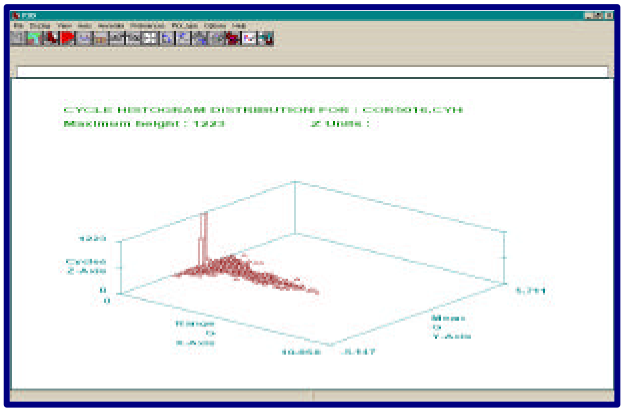
26 Road Route Surfaces = 2080 signals ~ approx 4 GByte

Preparation



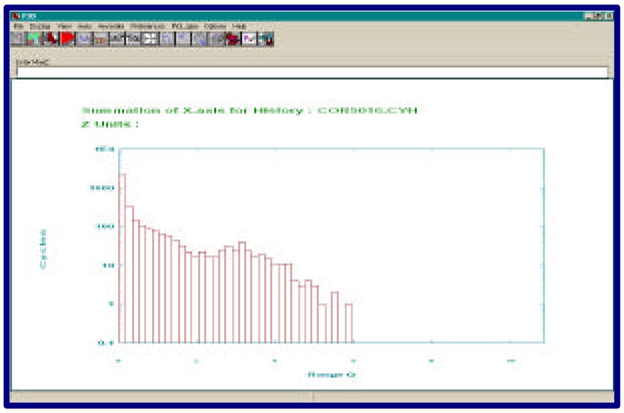
Iveco obviously gave some notice of the project, requesting from Australia the help and technology transfer. Initially, nCode Project Group, used the internal data management structure (NDMS), and a well-established directory & file naming strategy on a suitably large computer to ensure that as much preparation could be carried out before delivery of the data itself.

Little extra pre-work could be established, but as much information as possible was entered in to the data structure (the NDMS) as possible before the data arrived. Also, the opportunity was taken to check test the algorithms, and software bulk procedures prior to running any real data. This resulted in a large set of custom procedures set up to perform the majority of the whole analysis 'automatically'.



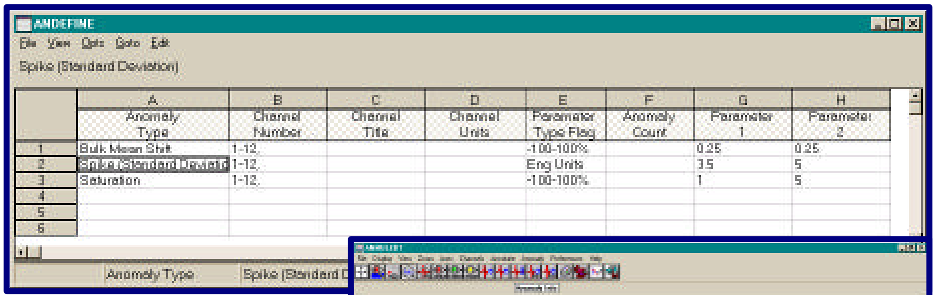
Similarly, the basic reporting and other statistical analysis procedures were set up to cover the tabular & graphical outputs from the library of established procedures collected over the past few years. It is this aspect of the correct use of experience, and the necessary organisation of information within a data management structure that ensures those large quantities of data to be handled easily.

It is important to remember that more than 80% of the work in any large analysis is in verification and classification of the raw data. If this can be handled by pre-organised and established - hence proven - standardised procedures, then the main complex analysis can be carried out in a much shortened time scale. A clear and logical plan of operation is essential to reduce the analysis time to a minimum, it is

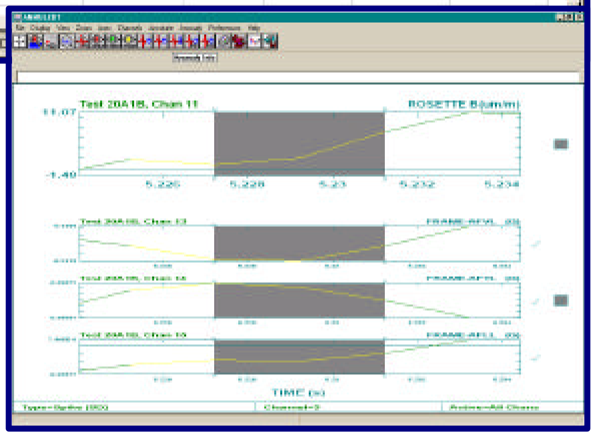


Day 1

Taking random samples of signal files to look for patterns of problems or other features requiring obvious correction inspected the data. The data was loaded in to the pre-planned directory & file-naming layout, and the initial procedures were run.

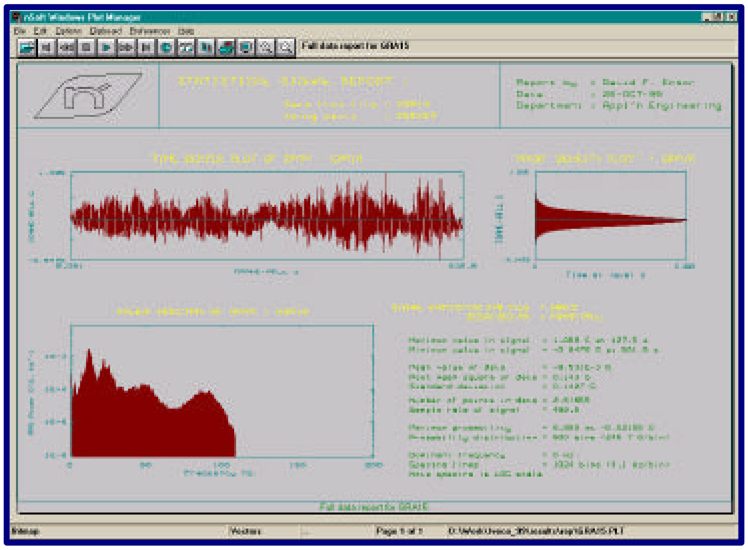


Sets of automated anomaly checks were performed on the whole data set. This was accomplished using the Anomaly Suite of software providing lists of possible problems along with graphical output highlighting the appropriate areas within the time series.



Where possible (most cases) the problems - occasional spikes, drifts, noise etc - were corrected automatically using spike detection and removal software along with filtering and drift correction routines.

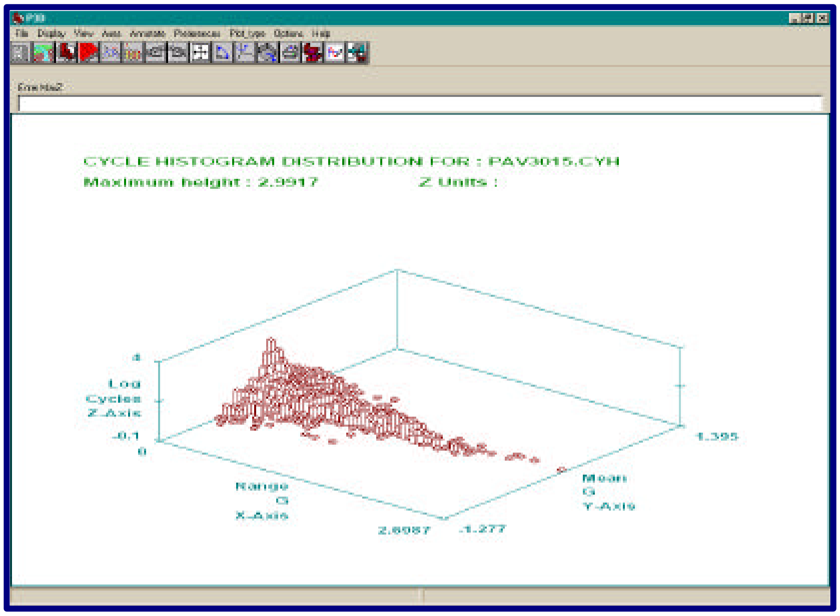
Obviously, during this automated process, it was also possible to produce full signal reports, classification to normalised rainflow, level crossing, amplitude distribution & frequency spectra for later analysis or load case requirements.



The majority of this was performed using overnight procedures to analyse all data and transfer results and classifications and store these results in an appropriate sub-directory structure. This efficient use of time allowed full experimentation during the day to ensure that the algorithms and processes worked accurately on a small sample of the data, and that full confidence could be assured on running the same procedures on the full data overnight.

Day 2

This obviously meant that the next day produced a full set of clean, verified, and classified data. This provided a full set of signals and other basic analysis results that could be accessed quickly and accurately from within the NDMS.



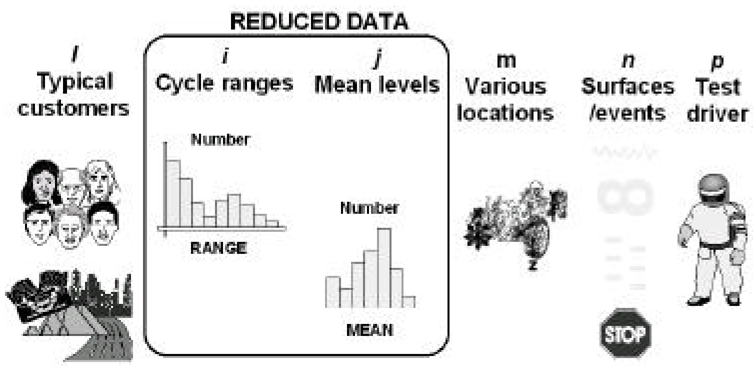
This also allows the more complex and involved analyses to be carried out directly from simple searches and links to appropriate data lists.

Using this information and the classification results for the road route collection it was possible to run an automated routine for assembling the target customer usage mixture. Thus producing a set of rainflow cycle histograms for each measurement area and scaled for the full target distance, from individual road data using an existing command language procedure. This particular procedure takes percentage mixes of road type, overall target distance, and rainflow cycle data for all the transducers & assembles a set of target rainflow histogram data representing the overall 95%ile usage. The software tools take little time on calculating this, the hard part is determining what the customer target should be.

Similarly, a larger series of connected procedures were used to provide a full set of classifications and time series data was assembled to represent the proving Ground information and special events required to produce the accelerated test procedure for Australia.

All of this assembled information forma the basic input to a full customer correlation exercise. The general background to this analysis requires a little explanation.

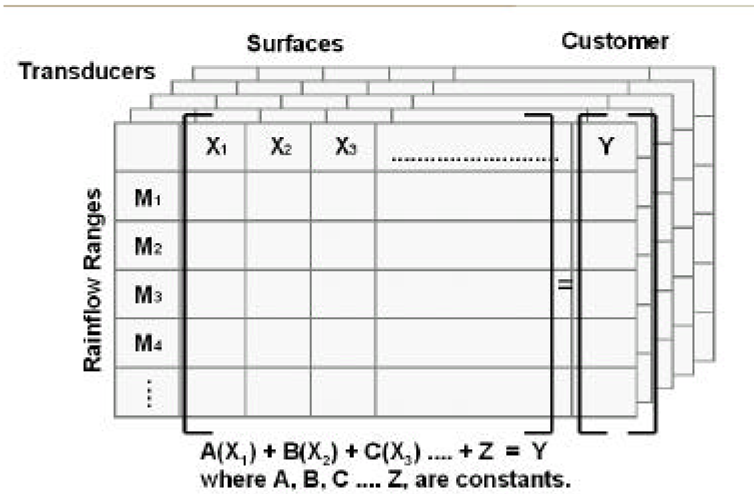
In recent years it has become easier and easier to collect and handle large quantities of experimental data. On-board data loggers, modern instrumentation advances, faster and larger computer storage also means that more complex software techniques can be applied. Some companies have already been collecting data from customer vehicles, even to the extent of basing loads and other test work on the results.



For some time now, discussions have taken place as to how to use this data to set realistic targets and standards to match what customers actually do with the product. It is now possible to use software tools as an aid to defining the optimum testing profiles or procedures to that of the customer usage pattern. Inputs will be required from 'standard' testing sequences and also customer usage measurements. These are then manipulated into a set of testing profiles providing inputs to the system that are the same as those experienced in reality.

It would be reasonable to assume that if the same inputs are reproduced that the same damage will result. Similarly, if the same inputs to the 'whole body' are reproduced, the associated transfer functions will take care of specific local damage changes, model to model, or design level to design level. It should also then be possible to determine accelerated testing procedures, where the same inputs are provided in a shorter period.

This diagram shows the data laid out for correlation.



It is then possible to find mixes of tracks or rig drives that match these inputs. Matrix calculations of various forms will then provide a scheme for assessing the mixture, and optimising test length or times, ensuring the same inputs are maintained.

Various mathematical methods can be used:

Simplex
Multiple linear regression
Canonical convolution
Relaxation methods

It now becomes obvious that matrix calculations can be used to produce a mixture of these tests.

These provide answers in the form:

$$A\,[X_1] + B\,[X_2] + C\,[X_3] + \ \dots + Z\,[X_n] = [Y]$$

Where	A, B, C, D, ...	= Multipliers of test data
	$[X_1]$, $[X_2]$, ...	= Matrix of test measurements
	[Y]	= Matrix of customer target measurements

This can be interpreted quite easily as: A times Track X1 followed by B time Track X2, etc. gives the same effect as Y of the Target.

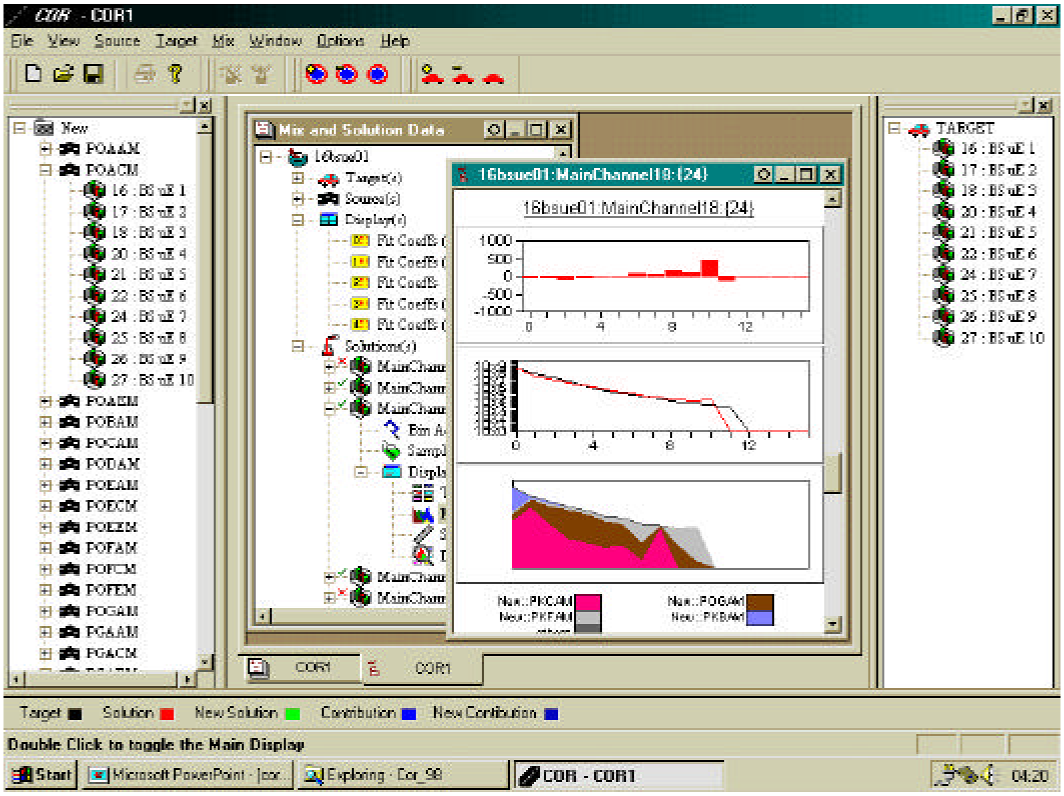
So mathematically we have methods that will provide mixes of test tracks and/or test rigs giving the same data measurements as the customer target. How can we interpret this in practice, and also does it provide accurate test procedures?

Acceleration

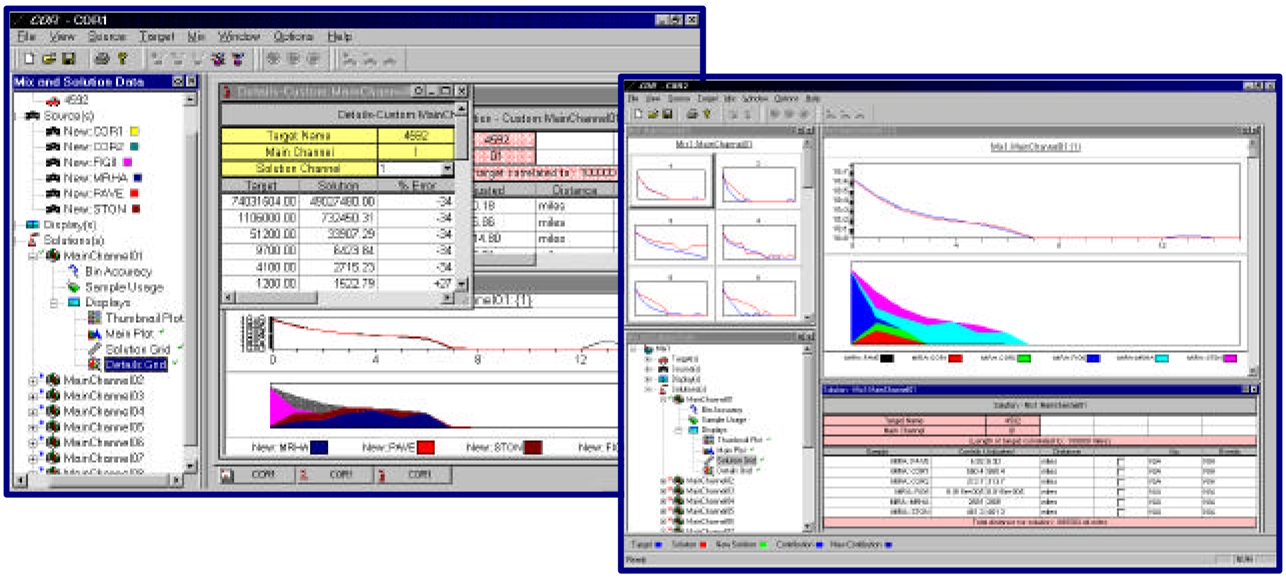
In every development programme, the need for shorter time scales is a necessity. So the resulting correlation mixes, (there are always more than one), can be assessed for criteria producing an accelerated overall test.

The Initial Correlation Output

The layout shows the track or event data (left window), the target or customer data (right window) and a portion of the workspace having various fit parameters and a typical solution. The solution shows an error plot (cycles), the target histogram (black line) and the resultant mix of test tracks & its fit (red line). The final plot shows a strata plot showing the contribution of each surface to the fit.



It is also possible to obtain exact numbers of events, distances, adjustment for practical testing and to derive the histograms for rig drives etc.



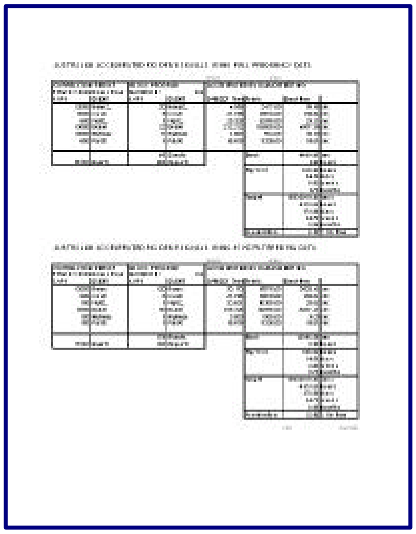
The plots on the right, describe various stages of adjustment, and other tables and information available providing invaluable information for track testing, design parameters, rig work, and other time dependant engineering processes.

It is even possible to immediately see the effects of changes, and even mix together existing target & test parameters and see how they fit the realistic target. It has been very enlightening to demonstrate how much of an overtest current working practices tend to be.

This method provide optimised mixes of tests, ensuring best fit cyclic histories for EVERY vehicle parameter, to a real customer usage pattern, in an accelerated test process.

Generally it is possible to split the results, and provide one of the following:

- i The shortest test time
- ii The shortest test distance
- iii The test using the most number of tracks



Most of the second day was spent in assessing and adjusting correlation mixes using multiple regression & least square fit methods to produce the appropriate track events, distances & number required that would reproduce the same cyclic vehicle inputs as the target usage.

Eventually, a further established set of procedural steps were used to reduce the overall mixture solution into a set of block programmes suitable for running as a realistic proving schedule.

The correlation produced a mixed set of track surfaces equivalent to 95%ile customer usage in Australia that would only take some 2 months duration.

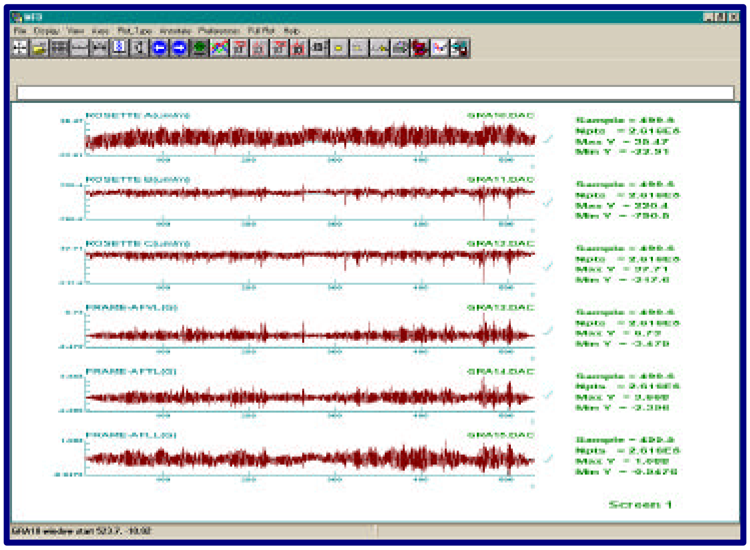
Software

nCode supply a suite of software (nSoft), also as an additional package to the standard analysis tools and fatigue analysis tools, they supply software for conducting correlation calculations and projects. nCode has very professional Engineers having experience within industry of correlation exercises. The Engineers involved have all been instrumental in developing the theory and practice outlined above. This experience can be passed on during Technology Transfer Projects where the methods and techniques are taught during the initial exercise.

The software itself handles the calculation of range summary files, correlation mixes, presentation and all other features required during the analysis stages of the exercise. The nSoft analysis suite provides the means for manipulating the road and track data into cycle histories and other data handling required. The integrated nature of the suite provides seamless working across the disciplines required. Due to the provisions of nSoft for handling very large quantities of data easily, the whole exercise becomes relatively easy.

The previous plots show one of the many typical result file outputs for a recent correlation study carried out by nCode Project Engineers. It shows some of the channels and surfaces used to perform the correlation study, and the resultant fit from the mixture of track surfaces.

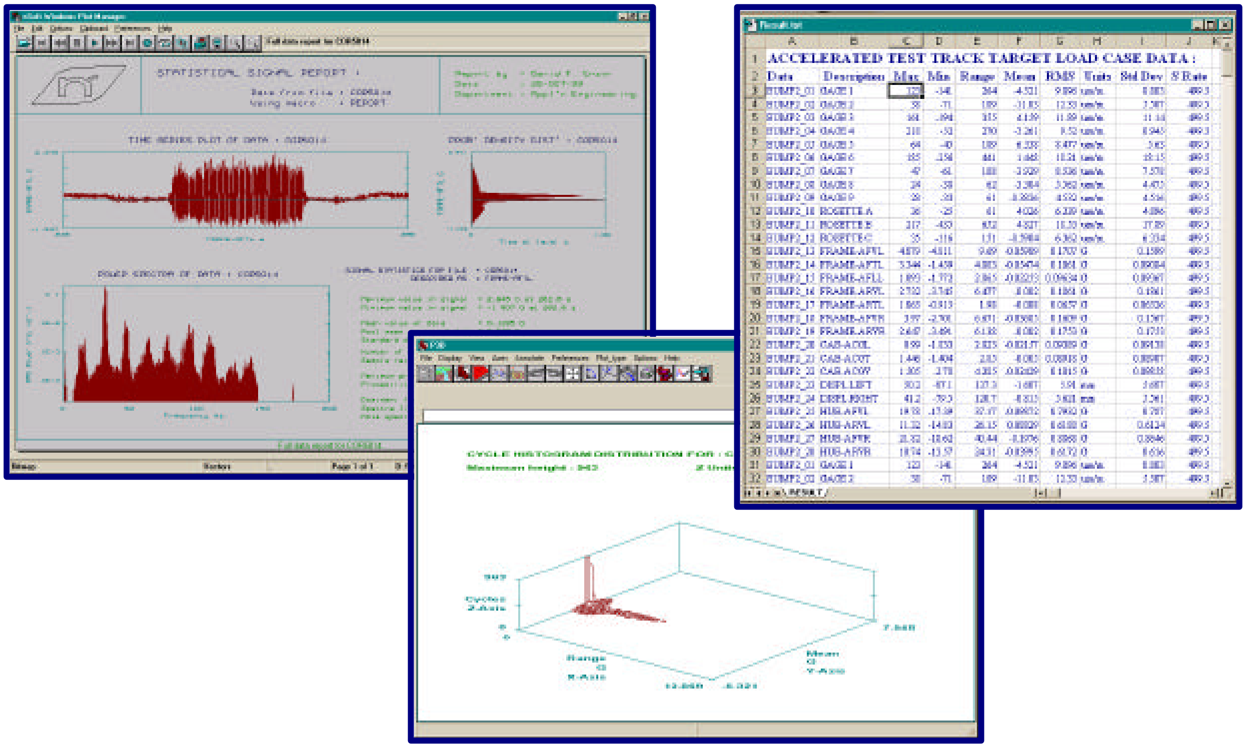
Day 3



Having now acquired a set of data classifications that together represent the real customer usage, it was possible to return to the time series data to supply test rig drive files.

These original data signals for strain gauges and load, displacement &/or acceleration values, can all be used as drive signals. So a large proportion of this day was spent in determining suitable algorithms, and especially using the various software tools available to provide rig drive signals.

All drive files required had the ends smoothed and manipulated to have sensible ramp characteristics for electro-hydraulic test systems, also certain signals were concatenated together, again with suitable joining and smoothing functions, to provide multi-axis drive signals.

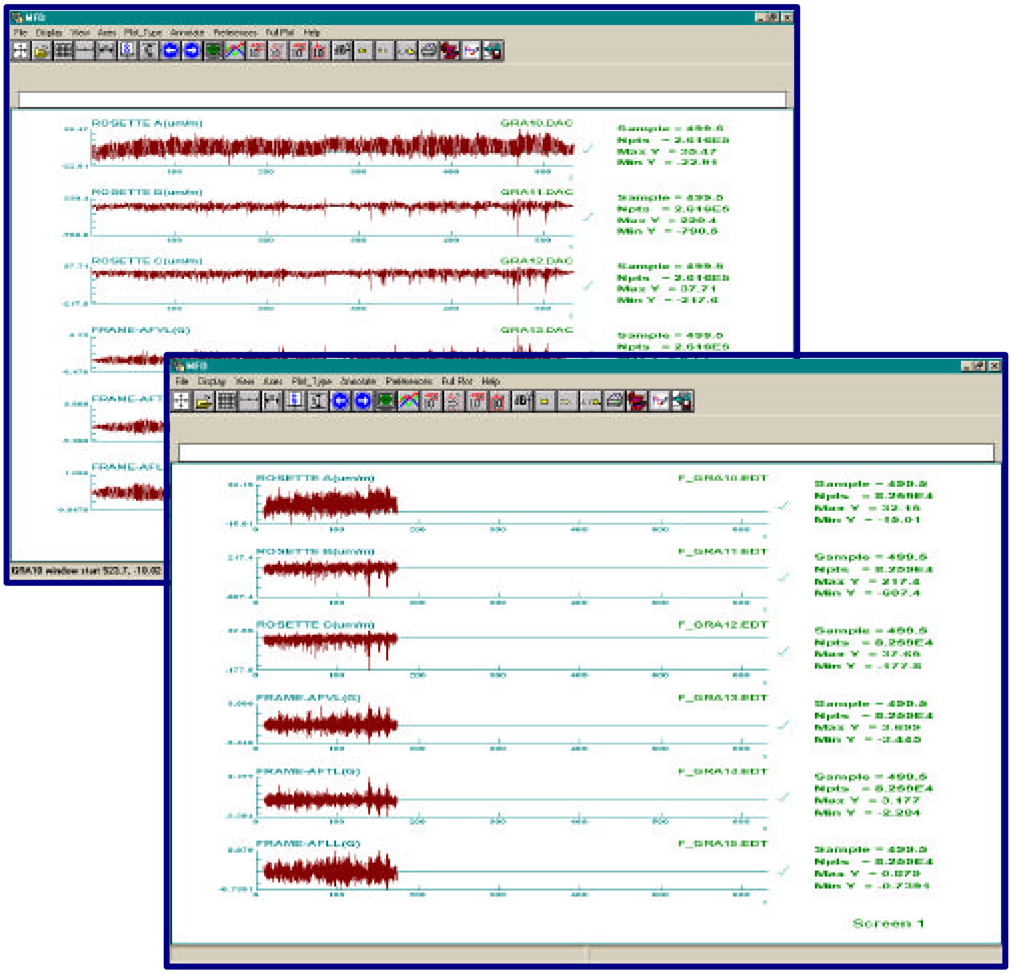


Following this the classification and other analysis results were entered into the data management structure & finally reported and tabulated using an automated procedure overnight.

Remember that the rig signals here will also require 2 months on the test rig, at the very least.

Day 4

Finally, there only remained one more items, Iveco had a specific need for an accelerated test of the body structure to pass of the vehicle design before Job 1. This required a test that must represent full 95%ile customer usage target but in a now very limited time schedule.



To provide this result a full session was devoted to multi-axis damage editing the drive files, but gating out all non-damaging portions of the test. This was carried out again using standard software tools that pass through the strain gauge signals assessing damage against time.

This is carried out for all important strain gauge positions on the complete body structure (12 in this case), and produces 12 damage time histories. Now all of these strain histories are also in time synchronisation with the rig drive signals. So all can be gated such that the parts of the drive signals are retained where any damage occurs at any strain channel, and discarded at any other. Of course due care is also taken to re-join any data gaps with sensible smoothing and joining functions.

The final result produced a set of drive signals, for the body structure, that reproduced all of the multi-location damage within a 3 week time period. It should also be noted that, throughout the analysis process, the correlation has ensured that the test still represents 95%ile customer usage in Australia.

Conclusions

It is possible using matrix techniques, good Engineering practice, and data collection techniques to produce accelerated vehicle proving tests that are based upon real customer usage conditions.

The experience of many exercises over the past few years has established many Accelerated Proving Test procedures based on Customer Usage targets.

Standards software tools are available to handle the large quantities of data, and to perform the matrix manipulations and fitting to the field data targets to ensure realistic and exact inputs are maintained.

In correlating customer usage to the internal design, development, & manufacturing targets ensures that all engineering work is optimised, both for time and loading cases. This will form the main basis in reducing time wastage, optimised proving cycles, and initial foundations of an Integrated Durability Management philosophy.

The main correlation produced a mixed set of track surfaces equivalent to 95%ile customer usage in Australia that would take only 2 months of track time.

A set of full vehicle rig signals were also available taking a similar 2 months on the test rig. Also the same signals could be accessed as a set of standard load cases, and design parameters as a library tool for future work.

The final result produced a set of drive signals, for the body structure, that reproduced all of the multi-location damage within a 3 week time period again equivalent to the 95%ile customer usage in Australia.

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