6th All-Wheel Drive Congress Graz

All-wheel drive between
motor sports and hybrid drive

February 3-4, 2005

Terrain Response, an Innovative Integrated Traction System for Land Rover Vehicles

>>

Ir. Jan P. Prins
Land Rover

MAGNA STEYR

MAGNA
MAGNA DRIVETRAIN

1 SYNOPSIS

Terrain Response is an innovative integrated system technology which addresses two issues at once. Firstly, it offers a simple intuitive control interface which integrates multiple systems such as hill descent control (HDC) and air suspension but also the engine, gearbox and traction systems. The new control interface addresses the issue of ever increasing complexity because of increasing numbers of individual system controls. Secondly, it widens the vehicles' breadth of ability by optimising many of the vehicle's systems for specific conditions, using the new interface. This provides a vehicle with a wider breadth and higher level of capability than otherwise would have been possible with a traditional single compromise for all conditions. This paper outlines details of the system and its development into a production system for the new Land Rover Discovery III and Range Rover Sport vehicles.

2 INTRODUCTION

Land Rover has always prided itself on producing 'The best 4x4xfar'. Its products have always excelled in off road performance and have often been perceived as 'best in class'. In July 2000 the Land Rover company was sold to Ford, by BMW, its owners of six years. One of the first tasks facing Ford and Land Rover was to re-start a Project to replace Discovery II. This Project was referred to internally as L319 and its niche-model sister the Range Rover Sport, as L320. Both models would be spun from a common platform, and both were to be fitted with a new technology now known as Terrain Response.

3 BACKGROUND

Under Ford, Land Rover is to strive for 'best in class' for Off Road Performance, in each market segment its products compete in. A lot of thought went into deciding the best traction strategy for the L319 and L320 products. Traction performance for the new models had to exceed existing Land Rover performance and match or exceed most of the competitors. Land Rover has pioneered the use of brake intervention traction control on off road vehicles but it was concluded that to meet the objectives, locking centre and rear differentials would be required. Ideally these would be electronically controlled devices.

In parallel to the driveline strategy, Chassis and suspension concepts had also been devised. Four wheel air suspension, HDC, brake intervention traction control and DSC systems would all be fitted to the new models. All in all, a wide range of technology and driver switched devices were being planned.

In anticipation of using all this technology, a relevant concept had been devised, based on a combination of two ideas. Firstly, that the many off road controls were getting complicated to manage by the average driver, and that simplification should therefore be considered. Secondly, that to improve a vehicle's performance for specific conditions, many of its systems' control settings should be configurable, rather than have one single compromise for all conditions. These ideas may seem to contradict each other, but it was possible to use both, by 'inventing' a system with a simple single driver interface that allowed multiple systems to be simultaneously switched to a range of settings optimised for different conditions. This system became known internally as 'Terrain Optimisation' (T.O.) but has now been put into production as 'Terrain Response', on the new Discovery III (LR3 in North America).

4 OPTIMISING THE VEHICLE FOR OFF ROAD

An experienced off road driver knows when to use the existing off road controls, such as differential locks, air suspension, HDC, etc. Through Terrain Response it was possible to add more controlled systems, without adding more driver controls. This allows optimisation of systems that hitherto had not been configurable by the driver. E.g. fine tuning the engine and gearbox control to specific conditions, as well as traction control sensitivity would all provide additional benefits.

The concept of Terrain Response is based on the driver 'optimising' the vehicle in a simple manner, for specific conditions. Whilst this sounds straightforward as an idea, to turn it into a working system, required some thought. What would be a simple and intuitive way for the average driver to 'optimise' a vehicle for a specific terrain?

It was decided to use a chunky rotary switch, befitting the Land Rover brand, allowing clear ergonomics and a presence in the vehicle interior. What had to be decided was how to define which terrains to group together for each setting. Rationalisation was required because it would obviously not be practical to have an individual setting for every possible terrain.

A list of about 50 distinct terrains was generated. For each sub-system to be linked to T.R, a limited number (in the order of 2 to 4) of different functionality assumptions were developed. E.g. 'cautious', 'normal' or 'aggressive' throttle or gearbox control, and 'sensitised', 'normal' and 'de-sensitised' traction control. A table was generated, listing against each single type of terrain which sub-system setting would be the optimum. By subsequently sorting the terrains by sub-system settings, groups of terrains were generated which shared common sub-system control settings. The terrains in the groups also shared common characteristics, such as 'slippery' or 'muddy'. The exact designations of the 5 groups of terrains that were formed in this way, as well as icons to depict them, had to be developed.

4.1 Intranet Survey I

An internal web-based (Intranet) Survey was compiled and sent out across employees of the Ford Motor Company and its sub-divisions (including Jaguar, Volvo, Mazda). This was to prove whether the principle idea and the proposed actual terrain grouping worked for the average customer.

4.1.1 Terrain Group Names and Icons

The following table shows the terrain group names and icons as used in Survey I:

Group Name	Button Icon
Standard	
Winter / Grass / Gravel	
Cross Country	
Sand	
Rock Crawl	

4.1.2 Survey I - Results

An expert panel considered the terrain pictures to identify the 1st and 2nd (where applicable) choice of beneficial setting for each photo, as well as those settings (where applicable) that would give a detrimental effect on vehicle performance. The choices made by the respondents were checked against the experts' decisions.

4.1.3 Survey I - Conclusions

The results from Survey I indicated that the principle idea of terrain mode selection, through provision of distinct general groups of terrains (surfaces), worked well. To improve the chance of beneficial selection, it was concluded that the terrain group names (Programs) and icons needed further development.

- New name required for cross country (include mud in the description)
- New name to be considered for winter-grass-gravel (include snow and/or ice in the description)
- New icon required for sand (no speckles and no sun to be included in the icon)
- Reconsider icon for winter-grass-gravel (too much of an on-road icon?)

4.2 Intranet Survey II

Although the first survey was successful, correlation between terrain and correct button selection was not strong enough, and the improvements to icons and Program names had to be validated with a second Intranet Survey. This Survey was split into two, with one half of the respondents only being shown the terrain icons, whilst the rest would see both icons and intended terrain group names.

4.2.1 Terrain Group Names and Icons

Between Survey I and Survey II the terrain group names and icons were developed. Three of the symbols were changed for Survey II. See table:

Survey I		Survey II	
Name	**Icon**	**Name**	**Icon**
Winter / **Grass** / **Gravel**		**Grass** / **Gravel** / **Snow**	
Cross Country		**Mud** / **Ruts**	
Sand		**Sand**	

With the exception of 'standard' and its icon, the names used in Survey II have been used for the production system. During development of the system it became clear that the name 'standard' and the icon of a vehicle on a flat road surface, did not adequately describe the intended use of the Program. In this Program the vehicle can still be used off-road, albeit not in automatically 'optimised' condition. The flat road surface was removed from the icon and it now depicts just a vehicle, without any indication of terrain. The Program is referred to on the production system as 'General', or 'Special Programs Off'.

4.2.2 Survey II - Results

The results showed that the version with text (as planned in the vehicle) gives a very good chance of a beneficial setting being selected. There is also less chance of choosing a detrimental setting.

4.2.3 Survey II - Conclusions

All objectives were met. The results proved that the intended grouping of terrains and the proposed names and icons for these groups can be used with a high degree of success when shown together. The average person will choose a beneficial setting with a high degree of certainty (>85%) and there is a sufficiently low risk (1%) of a detrimental choice being made. Please note that these results were achieved with respondents who were entirely unfamiliar with the concept and that both these results will improve further when drivers get familiar with the system.

The results achieved without the benefit of text with the icon did not meet the objectives and are not acceptable for a system in a vehicle. A text message centre or similar device is therefore a requirement for a T.R. type system, to display the terrain Program name information as well as a corresponding icon.

Using the Intranet for both Surveys proved extremely effective and a very high response rate was achieved, possibly helped by offering some small prizes.

5 HUMAN MACHINE INTERFACE

Basic requirements for the integrated Terrain Response ECU and switch are:

- Allow selection of Terrain Response Programs.
- Co-ordinate the active Terrain Response Program in all sub-systems.
- Inform the driver of the active and chosen Terrain Response Program, in two ways:
  - Illumination of icons on the switch itself.
  - Display of text and graphics on the instrument pack LCD (liquid crystal display).
- Provide advice and/or warnings or information:
  - Display of text and graphics on the LCD, to depict advice and warnings.
  - Sound an audible warning with some of the text displays, to draw attention to them.
- Detect and record diagnostic information
  - Checking for any faults with sub-systems, CAN network or the T.R. switch / ECU itself.
  - Record T.R. Program usage information.

Additionally the whole vehicle HMI was considered. Changing the T.R. Program will lead to automatic changes in sub-systems, and this may not always be appreciated. Therefore all such changes, as for example the switching of HDC or the air suspension, are clearly confirmed to the driver.

5.1 Program Selection

The active Program is indicated by illumination of the corresponding icon on the switch. When the switch is turned then a second Program icon is illuminated to indicate which position the switch is 'pointing' at.

Rotation of the switch also triggers text and graphics to be displayed on the LCD in the instrument pack. The graphics show all T.R. icons, highlighting which is being 'pointed' at., and this moves with the selector movement.

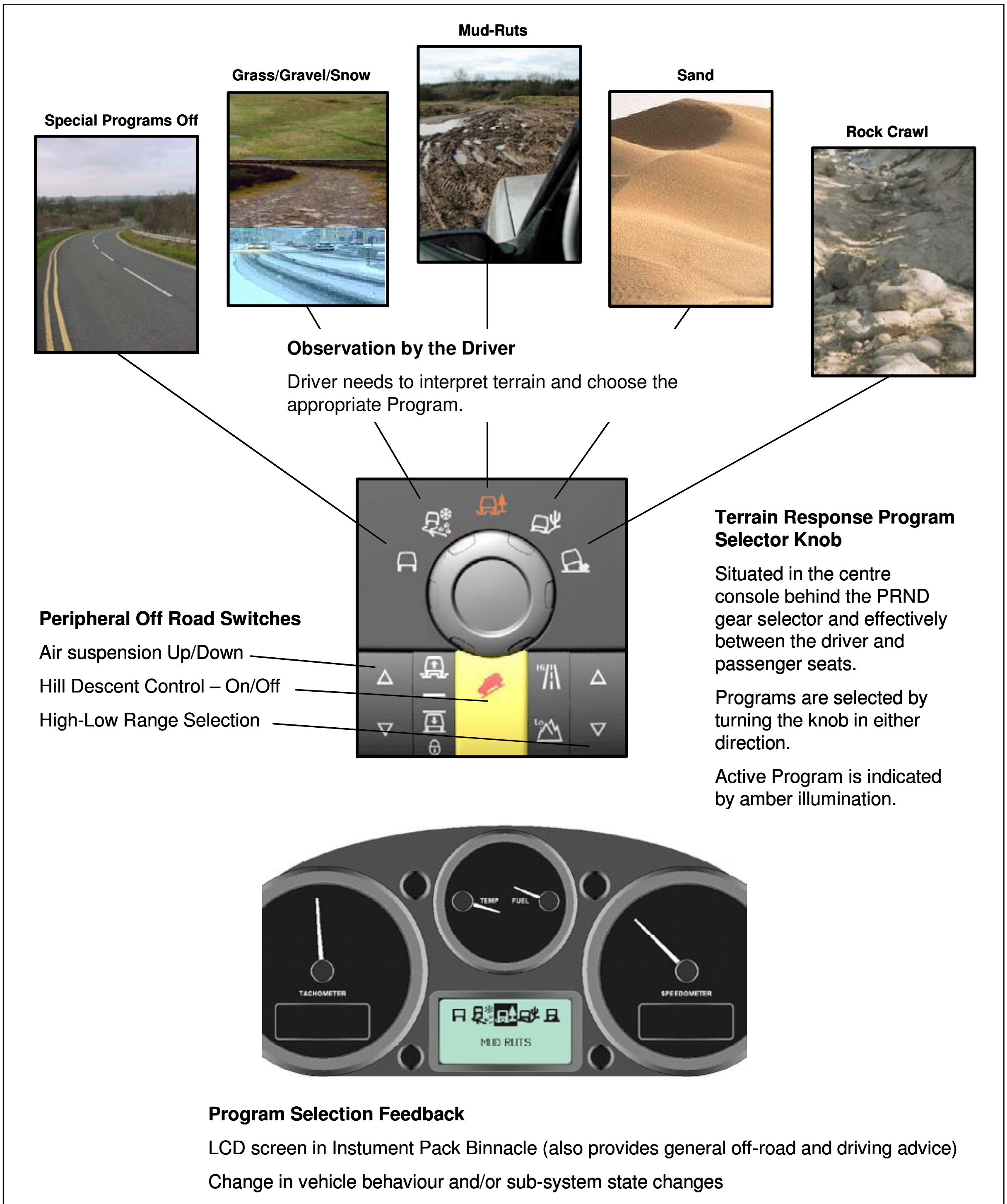

Figure 1: Terrain Response HMI

5.2 Program Activation

When a new Program is chosen, the T.R. ECU initiates the changes on the vehicle. Completion of the Program change is confirmed by the icon for the originally active Program extinguishing on the switch, and via text and graphics on the LCD.

The T.R. ECU ignores switch rotation whilst the engine is not running. This is deliberate as Program changes may otherwise go un-noticed. The switch has no physical end stops, but rotation beyond the extreme left or right positions of the switch is ignored.

Activation of some of the T.R. special Programs has implications to how the vehicle will behave. This may not always be appreciated when a Program has accidentally been left engaged, or if a different driver gets in the vehicle with a special Program active. Therefore there is a permanent display on the LCD to remind or inform the driver when a T.R. special Program is active.

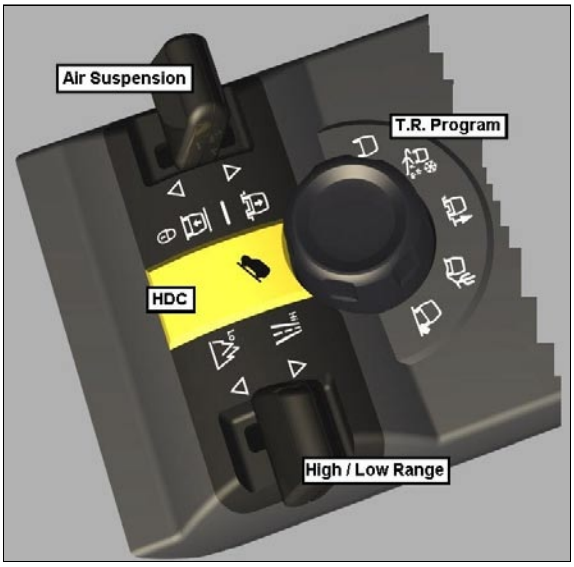

Figure 2: L319 Terrain Response Rotary Knob

When ignition is switched on, the T.R. ECU determines whether to default the previous Program to 'Standard', depending on the previously active Program and on how long the ignition has been off. All special Programs, apart from Grass-Gravel-Snow will default after 6 hours. The Grass-Gravel-Snow Program remains selected regardless of how long the ignition has been off, because this can be of benefit to customers living in extreme (winter) climates.

5.3 Driver advice or warnings

A key point of Terrain Response is that the system provides various aspects of advice and warnings, much like an off-road expert sitting with the driver, might do. Messages are shown concerning the following:

- Advice on which gear to select on manual transmission vehicles
- Advice regarding manually selectable options
  - Off road ride height (when not selected automatically)
  - Transfer box range
  - Program change is in progress
- Warnings related to the air suspension system
  - Trailer may be connected
  - Air suspension not at the off road ride height when it would normally be automatically selected
  - System faults

There are also confirmation messages from the sub-systems when their status changes. This is important because drivers may not appreciate changes in sub-systems, as a result of a T.R. Program change.

5.4 Steering indication

The T.R. system also provides an indication of whether the front wheels of the vehicle are approximately in the straight ahead position, or whether they are pointing to one side. This knowledge can be beneficial when the steering wheel is apparently in the straight ahead position whilst the vehicle is moving in a straight line, but only by virtue of a deep rutted track. As the vehicle comes to the end of a rut, with the wheels pointing to one side, then it will veer to that side. A graphic display in the instrument pack alerts the driver when a certain amount of steering is applied, hopefully resulting in corrective action being taken in time, as necessary. The steering information is shown in low range when the system is in one of the special Programs.

5.5 DIAGNOSTICS

In some cases the T.R. system may be inoperable. This will normally be indicated to the driver by permanently switching off all icons around the switch and displaying a text message warning.

The T.R. ECU contains diagnostics which detect problems with the T.R. system or switch. Where possible the T.R. ECU will request a fault message display at the occurrence of a fault, whenever a Program change is attempted to be made, and at any start up with a fault present. If the T.R. ECU is unable to request a message, the instrument pack automatically displays a warning.

The T.R. ECU monitors the amount of time and distance travelled in each of the different T.R. Programs. The purpose of this is to detect any possible misuse or even abuse of the system as well as being of relevance with regard to emissions and fuel certification. The Program usage information is stored in the T.R. ECU and is available through diagnostics.

6 TERRAIN SETTINGS

The Terrain Response system was extensively developed in a wide range of conditions. It was tested from the frozen lakes of Northern Sweden to the hot sand deserts of South Africa. Testing often involved multiple disciplines, such as engine, gearbox and traction experts, as well as Terrain Response Team members.

Two key attributes that were to be improved via Terrain Response, were traction and more particularly 'composure'. Both these attributes, and especially composure, are very difficult to measure or assess objectively. This makes it difficult to prove that development progress is being made, or how good the off road performance of the final system is. However, the development of Terrain Response has been carried out by engineers with considerable off road experience, who were able to use methods of subjective performance assessments, in a relatively systematic and objective way.

6.1 General Program

In this setting the systems will function generally as on vehicles without Terrain Response, using thresholds that give a general compromise optimised for all conditions, and in particular for on-road behaviour, The vehicle will still perform admirably well in severe off road conditions, even when used in the general program. All systems respond to the prevailing conditions, but can not anticipate them based on the Terrain Response program. It is of course this anticipation of prevailing conditions that provides some of the benefits when the special Programs are used.

The 'General Program' compromise can be different than that developed for non-T.R. vehicles, because on T.R. equipped vehicles the General Program compromise does not need to cover the most extreme conditions and may not need to be as compromised as otherwise, since these extreme conditions are better covered by the appropriate T.R. special Programs.

6.2 Grass-Gravel-Snow

In this setting the individual systems revert to control software which optimises the sub-system, and thus the vehicle traction, handling and driveability, for low μ conditions. When driving on ice or wet grass it is particularly important to avoid wheel spin when driving off, because any wheel spin will change the surface, and reduce traction below the original low level.

The Program was specifically tested under low (conditions in Northern Sweden, both on frozen lakes as well as on inclines. Particular emphasis in this Program is on modifying the powertrain torque delivery and avoiding wheel spin, by applying torque to the wheels gradually and by sensitising the traction systems. In addition to Northern Sweden this Program was also tested on gravel surfaces in both the UK and Belgium and on grass.

6.3 Mud-Ruts

This Program optimises the vehicle for driving on mud and in deep ruts. The mud may be dry or wet and slippery. Grip will often be limited and a lot of axle articulation may be required. There may also be steep up or downhill conditions and often the vehicle will be driving in deep ruts, giving rise to specific issues, such as extreme 'tram lining' or grounding out. Avoiding wheel spin is not so crucial on mud but maintaining engine torque is important.

The Program was predominantly tested in the UK, using forest tracks at various off road facilities.

A particular dilemma with the development of this Program concerns two contradictory aims. For driving in the mud it is beneficial to use engine torque rather than power and this can be achieved by the gearbox changing to a higher gear earlier than usual, thus keeping the engine revs low and in the region of peak torque. The dilemma with this is that this reduces engine braking when going downhill. Specific gearbox strategies had to be developed to find a compromise.

6.4 Sand

This Program optimises the vehicle for driving on sand. The Program is optimised specifically for deep and soft sand, which is often also very fine, and which is typically found in deserts. This Program was almost entirely developed outside the UK and work was carried out on three different continents. Desert and sand dune areas in the USA, South Africa and the Middle East (Dubai) were used.

Sand provides quite reasonable levels of grip but any wheel spin causes a vehicle to sink into it, and therefore all systems aim for a cautious take off. Otherwise, driving on sand causes a high resistance and a lot of power is required to make progress. The engine and gearbox need to combine to maximise the power whilst for example the DSC (dynamic stability control) system must try and avoid any power reduction requests.

The main issue with the Sand Program concerned the dilemma of avoiding engine torque reductions when driving in the sand, versus the requirement for the DSC calibration to still give an acceptable vehicle handling when the Sand Program is used inappropriately on the road, or on a low (surface. It proved that mere calibration differences in the DSC algorithm were not sufficient to achieve the desired reduction in engine intervention. Specific DSC logic had to be developed to achieve this.

Other issues were caused by characteristic sand corrugations which caused a very typical wheel bounce. This initially confused the DSC system.

A further issue concerned the requirement for the vehicle to meet stringent emissions legislation, in all high range T.R. Programs. This meant that some compromises had to be made in for example the transmission calibration.

6.5 Rock Crawl

This Program optimises the vehicle for driving over big rocks or boulders or other unyielding obstacles. Such obstacles often require extremes of axle articulation, causing wheels to be unloaded or to lift off the ground, causing a risk of them spinning up.

The rocks or boulders may only provide limited grip, particularly if covered in dust or mud. The extreme conditions make it important that progress is carefully controlled and slow. The Rock Crawl settings are selectable only when in low range. It must be made easy to edge a vehicle over the obstacles by careful modulation of the throttle. Torque at the wheels must build up carefully to slowly climb obstacles, but reduce quickly as the obstacle is scaled, to avoid overshooting. In order to improve grip and vehicle composure it is important to avoid wheel spin as much as possible. Particularly when wheels may be up against steep obstacles and the vehicle is also going up a steep incline, it is essential that any sub-system torque reduction requests (e.g. from DSC) are minimised and that torque at the wheels is maximised by providing the lowest gearing possible.

This Program was developed in the USA and in the UK. Specific issues in this Program concern the extremely low vehicle speeds, which give a very low resolution of the wheel speed signals used by the T.R. sub-systems.

6.6 Driver Choice

Where a driver is offered a choice in system settings, it becomes possible that inappropriate choices are made. The Terrain Response system does not include any terrain recognition and is therefore not able to check or correct a driver's selection. In addition it is possible that the T.R. Program is inadvertently changed by either driver or passenger because of where the selector knob is situated (centre console between the front seats). Bearing all this in mind, various precautions have been taken.

Firstly, and most importantly, it has been assured that the vehicle behaviour is safe on any known surface, using any of the available T.R. Programs, regardless how 'inappropriate'.

Secondly, there is a permanent indication to the driver, via the LCD message centre, that a Terrain Response special Program is selected. Most Programs will also be automatically de-selected after a certain amount of off time, so that they will not be accidentally used the next day or journey.

Furthermore, to reduce the likelihood of Special T.R. Programs inadvertently remaining selected, some sub-system functions are 'locked out'. For example cruise control and gearbox Sport mode are not always available. This locking out of special functions is intended to prompt the driver to deselect an inappropriate T.R. Program, and to discourage inappropriate use of special Programs. Finally, the relatively extreme Rock Crawl Program is only available in low range.

7 TERRAIN RESPONSE SUB-SYSTEMS

The requirements for sub-systems controlled via Terrain Response are to provide the following:

- Functionality specific to each Special Program.
- Functionality specific to changes of Program.
- Specific behaviour for special sub-system conditions (not faults).
- Specific behaviour for sub-system fault conditions.

Terrain Response sub-systems on L319/L320 exist of:

- Engine management
- Gearbox Control (where automatic gearbox is fitted)
- Driveline Control (electronically controlled centre and optional rear differentials)
- Stability Control System (ABS, Traction Control, HDC, DSC)
- Air suspension
- Instrument pack message centre (LCD)

Specific functionality for these systems has been developed for the Terrain Response system. The fundamental philosophy here is that each system is optimised in its calibration or functionality, and is switched to a condition which is most likely to be of benefit to the driver, i.e. it is most likely to be of benefit to have HDC switched on when driving in mud and ruts. However, the system offers the flexibility of switching sub-systems manually, overriding the automatic choice. It is always possible to manually control the air suspension, or to switch HDC or DSC on/off.

Of course it is not mandatory to use the T.R. system. The vehicle will still perform admirably well in severe off road conditions, even when used in the T.R. General Program. It will just not perform as well as in the appropriate Program because it will have to respond to the prevailing conditions, rather than being able to anticipate them. Furthermore, some systems, such as the engine and gearbox, will be optimised for on-road driving, when in the General Program,. It will be possible to drive off road using those settings but this will require more driver skill. In particular a very careful modulation of the throttle pedal and manual shifting of the automatic gearbox (using CommandShift) will be required.

7.1 Engine Management

The basic requirement for the engine management with regard to T.R. is to offer pedal progression maps which are specifically adapted for each Special Program. For each different Program there is a different relationship between throttle pedal position and the amount of engine torque produced. Additionally the rate of torque build up (or reduction), following pedal movement, depends on the active T.R. Program.

An additional requirement is that Program changes can take place under as many circumstances as possible, including whilst the throttle pedal is applied. Having to release the throttle, or not, can make the difference between maintaining momentum, or getting stuck off road. When changing from one Special Program to another, whilst the throttle pedal is applied, there needs to be a change in engine torque, even with the throttle pedal not being moved. This function is referred to as 'blending'.

Blending means that an engine torque change will occur, even when the throttle pedal is kept stationary.

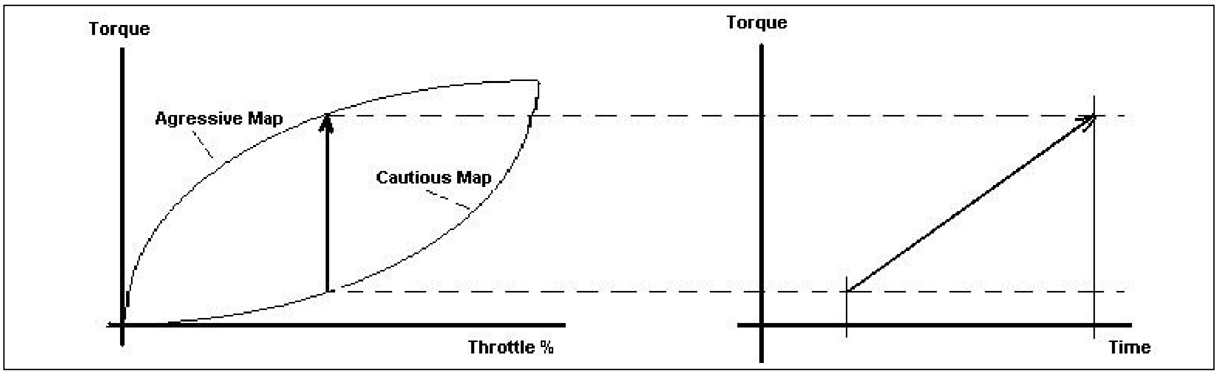

Figure 3: Principle of Throttle Map Blending

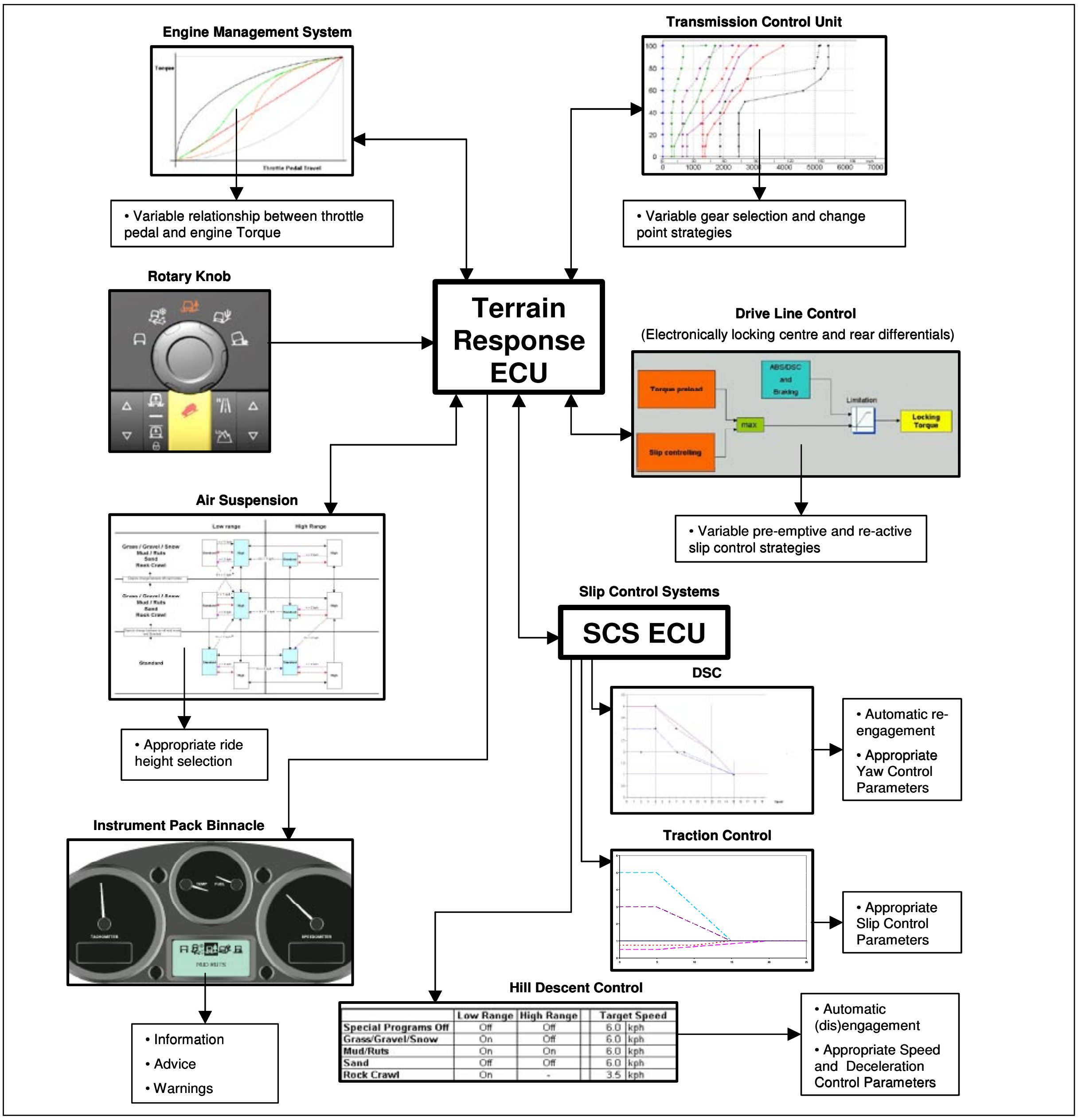

Figure 4: Terrain Response System Schematic

This change of torque will have the effect of accelerating or decelerating the vehicle, even though the throttle pedal is not moved, which can be unnerving. For this reason the rate of increase of torque has been very carefully tuned and has been set to a very gradual, albeit noticeable, level.

7.2 Automatic Gearbox

The basic requirement for the gearbox management system is to offer shift schedule maps, which are specifically adapted for each T.R. Special Program. This includes strategies in the Rock Crawl Program that ensure engagement of 1st gear in low range, which is otherwise unusual because it gives such an extreme short overall gear ratio.

7.3 Drive Line Control

The 4x4 driveline on T5 consists of a transfer box with high and low ratio, which includes an electronically controlled centre differential. Drive line torque will normally be split 50-50 but locking the differential allows this to change.

An electronically controlled rear differential is an option. The rear axle differential is controlled via the centre differential ECU, and its control is thus also optimised.

The basic requirement for the electronically controlled differentials is to offer locking torque levels across the centre differential and rear differential, as appropriate to the active T.R. Special Program.

The locking torque levels will be based on many dynamic vehicle parameters, which determine an amount of pre-emptive lock as well as any appropriate locking or unlocking response to a change in dynamic conditions (e.g. cornering). Any change in locking torque because of a change in TR program, is applied gradually, to limit any effects on vehicle handling.

7.4 Stability Control System

The T.R. functions for the Stability Control system (SCS) relate to traction control, DSC (dynamic stability control), HDC (hill descent control) and the ABS (anti-lock braking system). The systems have appropriate threshold settings but in some cases also functionality (i.e. control logic), related to each T.R. Program.

The status (i.e. 'on' or 'off') of the HDC and DSC systems is changed based on the active T.R. Program. With regard to HDC this can be both switching on, as well as switching off. Any switching of DSC only concerns re-activation.

7.4.1 Hill Descent Control (HDC)

Hill Descent Control (HDC) is switched on automatically in some T.R. Programs and the off again, in others. This functionality is achieved via a table in the SCS ECU, which 'knows' when to activate HDC or not. If HDC is switched on then the brakes are applied as necessary, and if the vehicle is going quite fast then brake force is built up gradually. Similarly if HDC is switched off because of a T.R. Program change then the brakes will be released gradually ('fade out'). Both these functions are part of standard HDC functionality.
Where HDC has been manually switched on by the driver, using the separate HDC switch, HDC remains switched on, following any T.R. Program change. Where HDC has been manually switched off by the driver, HDC engagement follows the defined table, following subsequent T.R. Program changes, with the SCS control ECU re-selecting HDC, as appropriate. This way the system allows flexibility within Programs, whilst erring towards caution with Program changes.

The SCS ECU applies different HDC control parameters, depending on the active T.R. Program. For example it selects the lowest possible target speed for Rock Crawl. Additionally, the HDC will brake more aggressively in some Programs but less aggressively in others, such as for example the low (Program, when grip is likely to be limited.

7.4.2 Dynamic Stability Control (DSC)

Where DSC has been switched off by the driver, it will automatically be switched on by the SCS control ECU, following any T.R. Program change, as a precaution.

The DSC applies different control parameters and in some cases special functions, depending on the active T.R. Program. The main aim is to reduce the likelihood of any torque reductions which are a side-effect of DSC activity. In off road conditions, any such torque reductions affect momentum, making higher demands for traction, which may not be available. This can particularly be an issue when driving in muddy ruts or when driving on sand. DSC bases its control on the typical relationship between steering input and vehicle dynamic behaviour (yaw), as it would be seen on a normal road surface with high levels of tyre grip. In ruts and on sand there can be a large deviation from the normal typical relationship, and this can lead to DSC activity and thus engine torque reductions, which are seen as undesirable under those conditions. Special functions had to be developed to recognise typical off road conditions and react appropriately.

7.4.3 Anti-lock Braking System (ABS)

The ABS control parameters or functions are in principle not based on the active T.R. Program. However, there are some special terrain dependent ABS control functions in the software which are only accessed within certain T.R. Programs.

7.5 Air Suspension

The air suspension will automatically raise the vehicle to increased off road ride height in some T.R. Programs, and when in low range. It will lower it again automatically when other criteria are met. This functionality is achieved by software functions in the air suspension ECU, which take into account the active T.R. Program and other vehicle conditions.

In the Mud/Ruts Program when in high range a text prompt is provided to driver, to consider selecting increased ride height for deep mud.

The general principle behind the switching of ride height with T.R. Program selection is that the vehicle is switched to a condition likely to be of most benefit with each T.R. Program and range combination. In addition, if it appears that the driver has made a deliberate choice to put the vehicle in off road ride height selection, then this condition will be maintained when a T.R. Program change is made. As with the HDC switching, this logic allows flexibility within Programs, whilst erring towards caution with Program changes.

The air suspension system receives a CAN signal indicating whether a trailer is connected. If a trailer may be connected then no automatic height rises will occur as part of any T.R. Program change. Instead, a text message warning is provided to indicate that no height rise has taken place because of the likelihood that a trailer is connected. The driver is then still able to manually raise the vehicle if desired.

8 SYSTEMS INTERACTION

The T.R. ECU communicates to participating systems and these systems 'handshake' with the T.R. ECU.

8.1 Program selection and mode changing

The T.R. ECU sends out the required Terrain setting via a CAN signal. Each of the participating systems is expected to follow the required Terrain Program, within a certain short time. The change of Program in the sub-systems is confirmed to the T.R. ECU in CAN signals unique to each ECU. At any time, a system changing to a different Program than that required will cause the T.R. ECU to disable the system.

Systems continuously indicate their availability to change their T.R. Program settings via additional CAN signals, also unique to each system. Special conditions which may not allow a Program change to take place in a particular ECU, are indicated to the T.R. ECU. For example dynamic conditions may prevail which make it impossible for a sub-system to change its active Program. For example when there is ABS or DSC activity. In this case the T.R. ECU will not change the Program, but will in stead request a warning to be displayed to the driver that indicates a temporary delay in activating the requested change. As soon as the dynamic conditions change and all systems can change their Program settings, then the T.R. ECU will activate the change immediately, if still requested.

There may also be sub-systems that have conditions that affect the whole T.R. System to such an extent that it should temporarily be disabled. Some sub-systems may have conditions, such as when they have overheated, which mean that whilst the condition continues, T.R. can not be supported. Without the support of all systems, allowing special T.R. Programs to be used would give new unplanned vehicle configurations, and this needs to be avoided. It is not acceptable for one sub-system to use default settings, whilst all other sub-systems continue using their special Program settings. Firstly, it would be extremely difficult to fully understand and approve all the unplanned combinations. Secondly, the unplanned combinations will affect the vehicle performance for the selected Program and this would be seen as inconsistent system behaviour, by the driver.

8.2 Fault behaviour

When the T.R. ECU detects a fault condition it disables T.R, extinguishes any Program selection indication and switches all systems to 'Fail safe default'. This condition is latched for the remainder of the ignition cycle to avoid intermittent system behaviour.

T.R. is switched off when sub-systems have faults. Without the support of all systems, activation of any of the special T.R. Programs would give unplanned vehicle configurations, which need to be avoided.

The T.R. ECU checks for the absence of T.R. specific signals from the participating systems. If any signals are missing T.R. will go to 'Failsafe default'. In turn, each sub-system ECU checks for the absence of the Terrain Program signal from the T.R. ECU. If the signal is missing the sub-systems unilaterally go to their failsafe default Program settings. Together, these principles mean that even if no CAN communication is possible between T.R. ECU and one or more sub-systems, that the vehicle is switched to a known safe condition.

9 SYSTEM DEVELOPMENT

The T5 platform is spawning the most technically advanced vehicles, with the highest level of vehicle system integration, ever undertaken within Land Rover, and possibly within the Ford Motor Company. This electronic integration of systems presented its own challenges. Communication between systems is via a state-of-the-art CAN system, designed in such a way as to guarantee signal timing requirements are met. However, the functionality of various integrated systems, their calibrations and what they communicate via CAN, under which circumstances, had to be carefully determined, often in joint testing between different disciplines.

Another issue, which is fundamental to the system, is that the Terrain Response system is an integration of sub-systems which all have their own levels of reliability and risk of failure. Unfortunately, the risk of failure of the Terrain Response system is equal to the sum of the risk of failure of all systems involved, and the total number of systems adds up to eight! Fortunately the vehicle reliability and validation testing has highlighted no issues specific to Terrain Response.

10 MARKETING TERRAIN RESPONSE

The predominant benefits of Terrain Response concern ease of use and improved vehicle composure and traction in off road conditions.

Through the improved vehicle composure the ride in the vehicle in off road conditions is more comfortable for the driver and passengers, and progress is smoother and more consistent. The improvements in traction as well as the improved composure, should mean that a vehicle employing Terrain Response will be treading more lightly than it would otherwise. There should be less wheel spin and the vehicle's path will be able to be chosen with more care to the environment.

The improved composure and reduced wheel spin will be of particular benefit to novice or inexperienced off road drivers who might otherwise be put off by excessive wheel spin or unsteady progress. Thus the system allows improved off road performance to be more easily accessible to all customers.

Previously much of the extensive technology used on Land Rover vehicles has been hidden 'under the skin', with the benefits of the technology fitted not becoming clear until a vehicle is driven off road. Even then customers did not always appreciate that the vehicle performed as well as it did because of the fitted technology. To them, the vehicle 'just did it'. With Terrain Response, the rotary knob in the vehicle centre console is a visual cue to the technology fitted and this may help 'sell' the extensive hidden technology.

Once the benefits of Terrain Response become clear, then Terrain Response may become a 'reason to buy' a new Land Rover vehicle. Much of Land Rover's off road performance is sold by press reports and 'word of mouth' praise by extreme users. This gives typical customers 'peace of mind' that the vehicle will do what they want it to do if the need arises.

Terrain Response will assist the consolidation of the Land Rover brand as the class leader in off road ability. With Terrain Response fitted to its vehicles this means Land Rover hopes to sell more vehicles more profitably than would otherwise have been possible. Terrain Response offers excellent marketing opportunities and the system has already featured prominently as part of the Discovery III Launch Campaign.

It is quite easy to show that each T.R. Program gives a different vehicle behaviour. To some extent the vehicle does not even need to be driven to appreciate that something happens when a Special Program is engaged, when for example HDC is automatically switched on. A subsequent short on-road drive will further show different vehicle responses, which will be noticed by any driver. For example the gentle torque delivery in the grass-gravel-snow program can be easily appreciated. The Marketing and Sales challenge with regard to Terrain Response will be to make customers appreciate how the perceivable differences in vehicle behaviour will benefit them. To really appreciate the benefits will require extreme off road conditions, in order to 'prove' them. Hopefully customers will see the press reports and other evidence that show vehicles successfully tackling the extreme conditions that they, and the Terrain Response system, have been developed for.

Terrain Response has given Land Rover a real competitive advantage. As a feature it is intrinsic to the brand values and will help maintain Land Rover's positioning as the off-road leader, with the added dimension of excellent on-road abilities, combining to give new Land Rover vehicles the widest breadth of capability in the market place. A real reason for customers to buy a Land Rover Discovery III or Range Rover Sport vehicle.

11 FUTURE DEVELOPMENTS

The Terrain Response system will be able to be expanded and further developed in various ways. The number of required off-road terrain settings has been proved to be four but the system could be expanded with on-road Programs.

If it is proved that drivers prefer to rely on the Terrain Response system to switch systems such as HDC or air suspension then it may be possible, over time, to delete some of the individual system switches. This would reduce flexibility and may not be appropriate to all Land Rover vehicles. However, it would give a simpler overall HMI and would reduce demands on packaging space and cost.

In principle there is no limit to the number of systems that could be switched and optimised for different conditions, via the Terrain Response system. Future T.R. systems may benefit from links with additional systems that may be applied to future Land Rover vehicles.

Additionally, in the medium to long term, Terrain Response could be expanded with elements of terrain recognition. In the very long term this may lead to a fully automatic system, thus further improving 'ease of use' and overall HMI.

12 ACKNOWLEDGEMENT

Terrain Response has been developed as an integrated system, across many different disciplines within Land Rover. Implementation of the system also relied on suppliers such as Bosch, Denso, ZF, and Magna-Steyr.

Everyone worked together and enabled Land Rover to meet its objectives. It was not easy to deliver both a completely new vehicle platform, two derivatives of this platform, as well as a new system, all more or less at the same time! Particularly a system as complicated, and with such a high level of integration, as Terrain Response. Land Rover is grateful to everyone involved in the development of the system, inside and outside of the Company.