Off-Road Leadership in the 21st Century
Introduction to the ‘Off-Road Capability’ Attribute

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Introduction and content

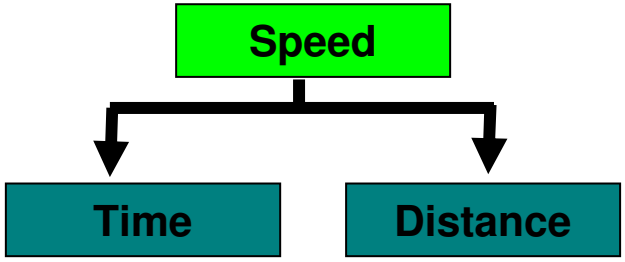
- Off-Road Capability definition
- Breakdown into Primary Surfaces and Sub-Attributes
- Quantifying Off-Road Capability
- Sub-Attribute definitions
- Balance of Off-Road Capability and other key factors
- Future
- Conclusion

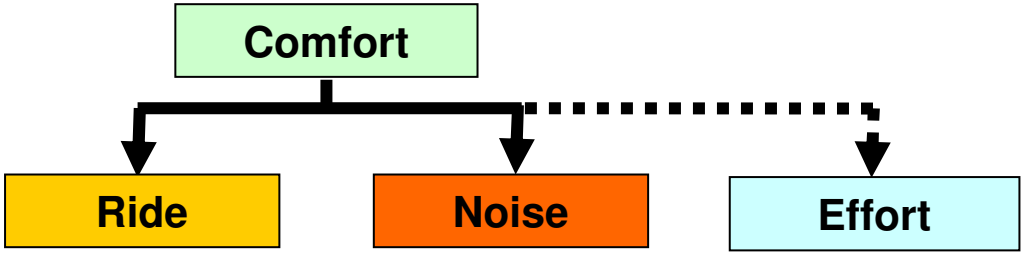
Off-Road Capability
Definition

"It gets there or it doesn't"

'Driving from A to B on off-road terrain'

Covering the distance from A to B
transporting occupants and payload
in an acceptable amount of time
with a minimum level of comfort for all occupants
not exceeding a maximum level of driver effort
and without causing damage to vehicle or terrain





Off-Road Capability
Definition ‘Primary Surfaces’

- Customers perceive many different types of surface conditions / terrain as “off-road”; including poor on-road conditions.
- At Land Rover we have categorised **7 primary surface** types:
  - Wet Grass
  - Snow / Ice
  - Gravel / Dirt Roads
  - Mud and Ruts
  - Sand
  - Boulder Crawl
  - Wading

Off-Road Capability
Direct influences on capability

‘Off-Road Capability’ is directly influenced by the following requirements:

- Desired speed over ground
- Desired level of occupant comfort
- No. of passengers / load to be carried
- Type of terrain to be traversed
- Size of obstacles to be traversed
- No. of times obstacles will be traversed
- Contact pressure of vehicle
- Slip / pull characteristics at contact patch
- No. & size of contact patches
- Power / weight & torque / weight values of vehicle
- Torque characteristics & driveline matching of power unit
- Drive torque distribution

Some of these requirements can be improved with technology (cost added), others can be met by good fundamental design

Off-Road Capability
Quantifying

Need to break down '**Off-Road Capability**' into measurable chunks

Measure key vehicle parameters and Sub-Attribute performance objectively

Key Parameters

> Which to measure – determine relative effect on overall 'Off-Road Capability' through correlation between parameters and capability

Sub-Attribute Performance

> What to measure - determine relative effect on overall 'Off-Road Capability' through correlation of sub-attribute performance and overall capability

> How to measure?

- Develop tools and techniques
- Use controlled subjective evaluation (expert jury assessment) - as with high level Attribute

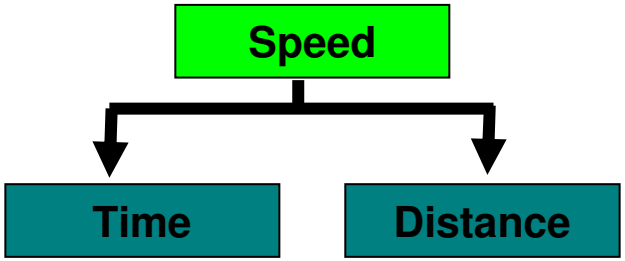
Developing objective measures takes time but progress is being made at Land Rover

Meanwhile we improve vehicle performance continuously using experience

Off-Road Capality
Definition 'Sub-Attributes'

'Control of Speed'

- > Ability to control speed over (difficult) terrain
- > Maintaining traction and avoiding or responding to wheelspin

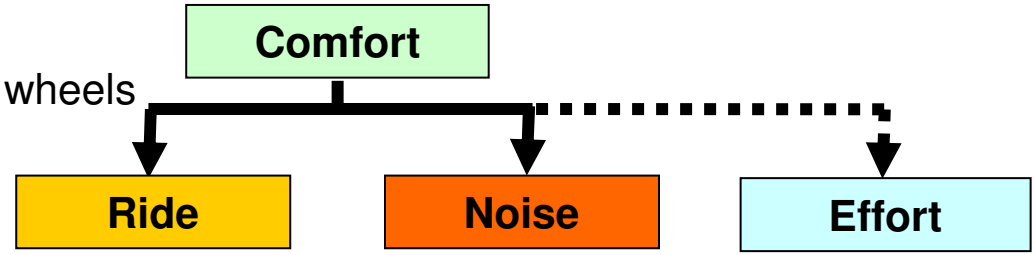


'Driver Effort'

- > Controlling speed (response to accelerator / brake)
- > Manoeuvrability (e.g. steering efforts and turning radius)
- > Field of view (ease of positioning the vehicle accurately on the terrain)
- > Control of relevant systems (e.g. gear, range, suspension, driveline etc.)

'Ride'

- > Vertical impacts to the vehicle from the wheels



'Noise'

- > Driveline noise
- > Tyre noise (e.g. wheel spin, stone strikes etc.)
- > System noise (e.g. engine, traction control, HDC® etc.)
- > Hard impacts with terrain (to body, suspension or driveline) – **vehicle base geometry is key!**

Off-Road Capability
'Control of Speed'

Controling vehicle speed when starting, stopping or driving off-road.

- Over obstacles and through difficult terrain (high rolling resistance)
- Going uphill
- Going downhill

To optimise:

- Low crawl speed (short gearing)
- Optimise torque delivery

Enablers:

- Wide gear ratio spread (twin speed transfer box), engine calibration & design, Terrain Response®, HDC®, Hill Hold, Crawl Control

Off-Road Capability
'Control of Speed' - Traction

- When driving 'Off-Road' there are often high loads to be overcome
  - > Resistance to motion (rolling resistance + drag)
  - > Gradient
  - > Climbing obstacles
- To overcome these high loads, application of high drive forces / torque is required
  - > Friction coefficient (grip) often limited
  - > Contact pressure (tyre loading) often limited

  } Limited tractive potential per wheel

  Hence all-wheel drive
- Torque needs careful control and distribution to those wheels that can use it, and vehicle control needs to be simplified, hence a need to:
  - > **Maintain contact pressure by good articulation & vehicle geometry**
  - > **Maintain traction by driving all wheels & controlling wheel slip**

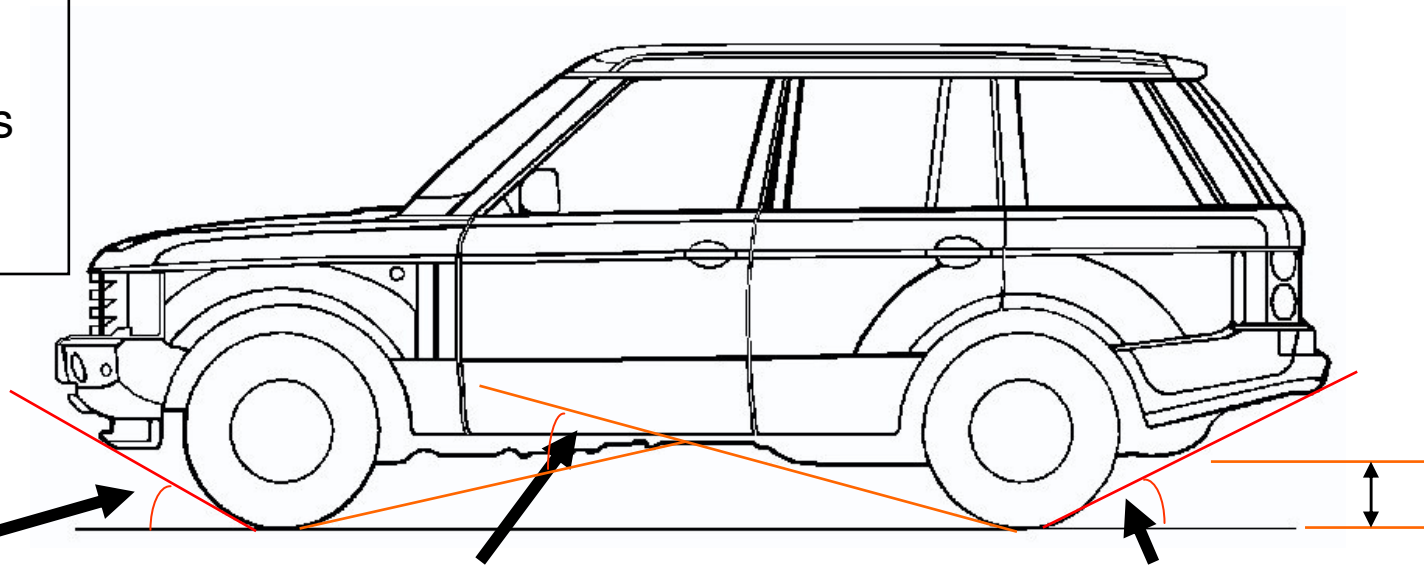
Off-Road Capability
Traction - Load on the tyre

Articulation affects ability to maintain traction

'**Articulation**' = 2 x Gauge height – height of tyre off ground

Off-Road Capability
Traction - Load on the tyre

Basic geometry affects ability to negotiate obstacles whilst maintaining traction



Approach angle

Ramp-over angle

Departure angle

Off-Road Capability
'Control of Speed' - Traction

To achieve and maintain vehicle motion the vehicle needs **'Traction'** to utilise the available grip and overcome resistance.

To optimise 'Traction':

- Drive all four wheels
- Control wheel slip (re-active and pro-active)
- Optimise weight distribution
- Optimise tyre contact patch pressure & tyre tread
- Avoid body contact with the terrain

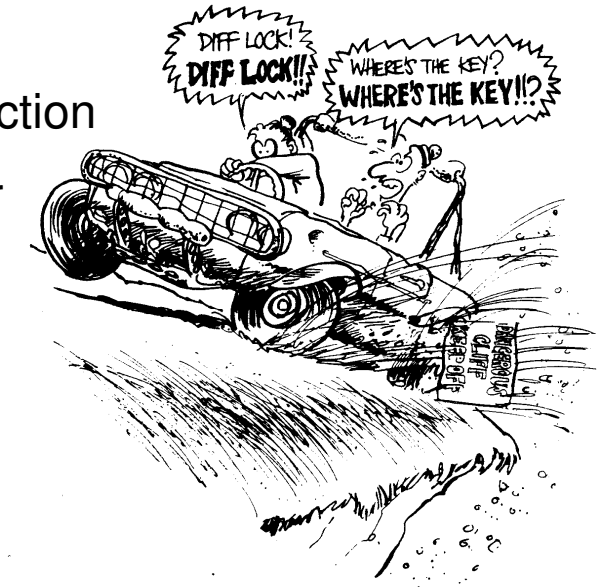
Enablers:

- Good fundamental design
- Brake traction control, eDiffs, disconnecting anti-roll bars, active roll control (ARC), air suspension with cross linking, Terrain Response®, central tyre inflation, off-road tyres

Off-Road Capability
'Driver Effort'

The physical and mental efforts required when driving off-road.

- Mental: Determining the best speed to use and ideal path to take & how to respond to 'unexpected' and sudden events
- Physical: Optimising the vehicle setting, speed and direction
  - > Control of normal drive systems (brake / accelerator / steer / gear) and Off-Road systems



To optimise:

- Add assistance systems
- Integration of systems
- Vehicle design (base geometry), ergonomics and HMI tailored to off-road driving

Enablers:

- Brake servo, power steering
- Automatic and integrated systems (Terrain Response®)
- Optimisation of vehicle design and package (internal & external), camera systems

Off-Road Capability
'Ride'

Off-Road Ride aspects of vehicle behaviour in response to vertical inputs through one or more wheels

- Ride
- Pitch / dive
- Rock (side to side)

To optimise:

- Compliant long travel suspension (soft springs)
- Low roll stiffness and/or even distribution of roll stiffn

Enablers:

- Optimisation of suspension design (long travel suspension with minimal weight transfer & roll stiffness)
- Disconnecting anti-roll bars, active roll control (ARC), active dampers
- Air suspension with cross linking, central tyre inflation
- Systems with multiple settings (dampers, ride height, roll control)

Off-Road Capability
'Noise'

'Noise' due to vibration, harshness and impacts as experienced in the vehicle by the occupants when driving off-road.

- Ride related response to vertical inputs through one or more wheels & tyres
- Body / trim noises (during off-road usage)
- System noises
- Environmentally caused noises

To optimise:

- Reduce levels of noise generated
- Insulate / hide noise
- Tune noises to appropriate sound quality
- Avoid body contact with terrain

Enablers:

- Tyre choice, material selection & sound deadening, reduced brake traction / DSC intervention (eDiffs) and/or system optimisation (e.g. ABS pump)
- Good fundamental design

Off-Road Capability
Attribute 'trade-off'

To achieve required levels of Off-Road Capability, Attributes need to be 'traded' (balanced) to achieve best compromise.

- Impact on Vehicle Dynamics
  - > Opposing requirements on suspension and tyres
  - > CoG height increase with high ground clearance
- Impact on Design & Package
  - > Approach, departure, breakover; wheel clearances, articulation (wheel travel)
  - > Wheel size & tyre sidewall height
- Impact on Vehicle / Pedestrian Safety
  - > Approach, bumper height, front end style
  - > Size factors & momentum

Some issues can be overcome with good fundamental design or technology, others must be 'traded'.

Depending on solution there can be an impact on Cost & Weight (and thus CO_2)

- > Added components / systems
- > Stronger components to meet durability requirements

Off-Road Capability
Capability vs. physical factors

Off-road capability is a continuum – ability to move a given payload across a surface at required levels of speed & comfort.

It is linked to (but not necessarily dependent on) cost & weight of vehicle

It is engineered to meet customer usage & requirements

Off-Road Capability
Capability vs. weight

Off-Road Capability does not *per se* add weight to vehicle

- Lighter weight vehicle improves capability
- Lighter weight vehicle reduces environmental damage
- Lighter weight vehicle has greater fuel range

But weight reduction can only be achieved by good fundamental design or by lightweight (≈more expensive) components

Similar capability

960kg **1725kg** **2500kg**

Increasing weight

Off-Road Capability
Capability vs. cost

Off-Road Capability does not *per se* add cost to vehicle

- Lower cost vehicles have similar capability to higher cost vehicles
- Lower cost vehicles typically are used more off-road

No clear correlation between capability & cost of the vehicle - low cost can be achieved by good fundamental design and compromise with other attributes

Similar capability

$20k **$49k+** **$70k+**

Increasing cost

Off-Road Capability
Technology

Examples of win-win for Off-Road Capability and other Attributes:

- Flat underbody (Aero and Robustness)
- All-wheel drive versus two wheel drive (Vehicle Dynamics)
- Air suspension multiple ride heights & cross-linking (Vehicle Dynamics, Aero)
- Active roll control (Vehicle Dynamics)
- Active damping (Vehicle Dynamics)
- eDifferentials / eCouplings / torque vectoring (Vehicle Dynamics)
- Central tyre inflation system (Vehicle Dynamics, Economy, Robustness)

Good fundamental design does not add cost or weight

But…

Additional systems add cost and weight, thus affecting other Attributes.

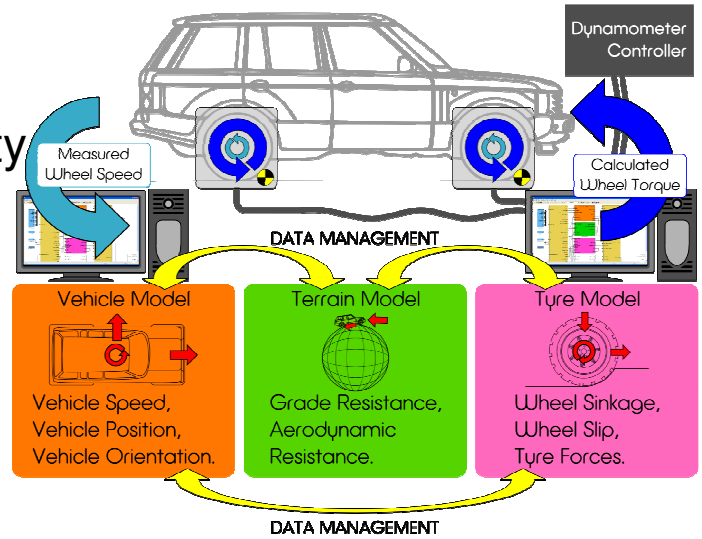
Although…

Some systems/features are ‘just software’. E.g. Traction Control, HDC®, Terrain Response® (other than the rotary selector).

Off-Road Capability
Normalising results

Off-Road Capability is very terrain dependent and so need to qualify the terrain

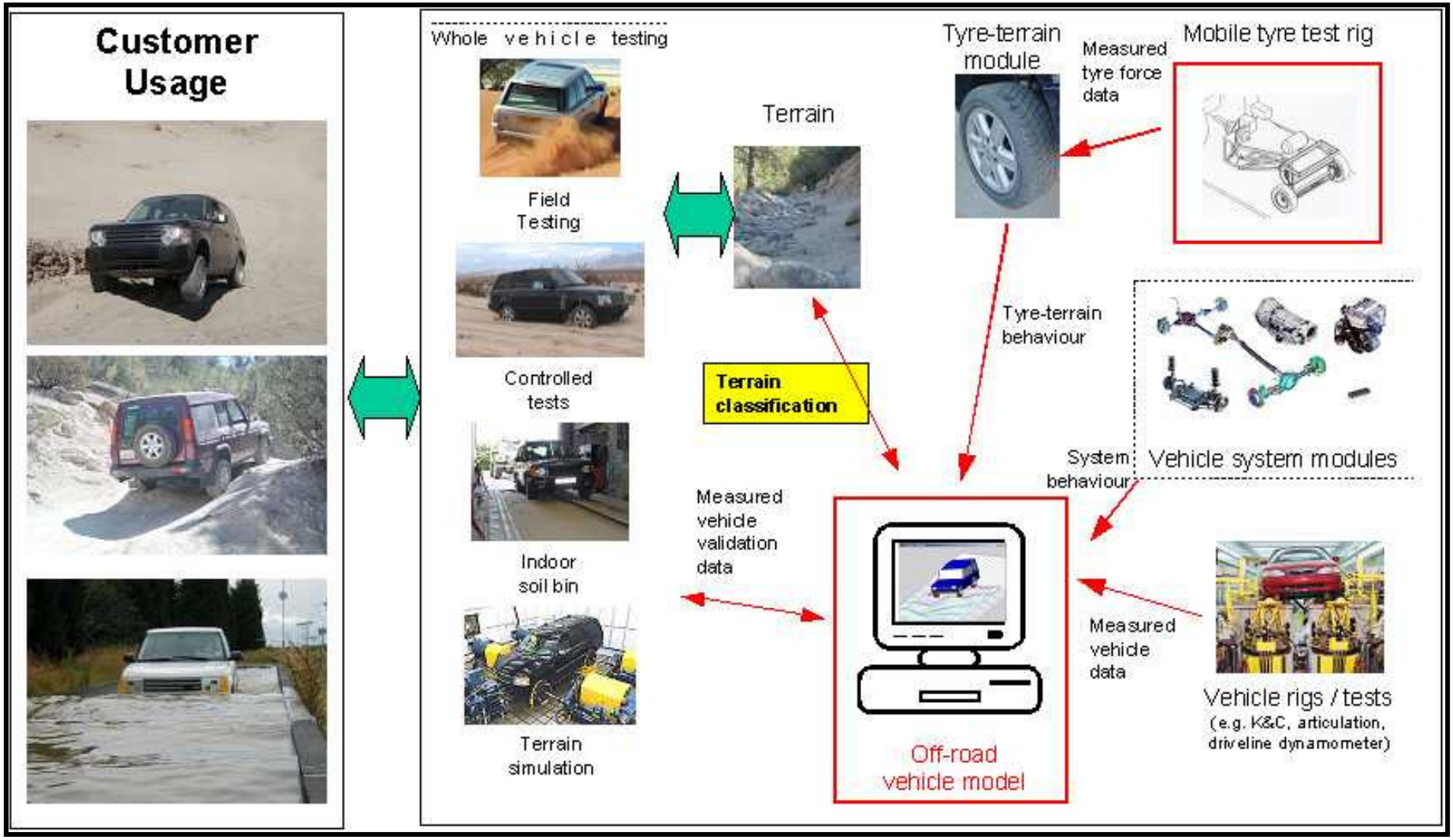
- Use a ‘control’ vehicle
- Control the terrain
  - > Off-Road Dynamics facility at Cranfield University
- Measure terrain (determine properties ‘on the day’)
  - > Terrain classification system being developed
- Reproduce the terrain artificially (dyno rig)



Aspirations:

- Normalise results based on terrain properties experienced during test
  - > Proposing a public standard Terrain Classification system
- Move emphasis from whole vehicle field testing to laboratory testing
  - > Test off-road capability on a rig (HIL)
  - > Model Off-Road Driving using CAE based on terrain measurements and RLD

Off-Road Capability
Future



Off-Road Leadership in the 21st Century
Conclusion

- Off-Road Capability is very important to Land Rover
- Achieving Off-Road Capability is a challenge
- Measuring Off-Road Capability objectively is hard but progress is being made
- Need to apply scientific approach to Off-Road Capability, in order to
  - > Develop capability further
  - > Develop objective metrics
    - Indisputably quantify Off-Road Capability
    - Meet development time requirements
    - Meet competitive position targets
  - > Aid decisions of compromise between Off-Road Capability and Vehicle Dynamics, and between Off-Road Capability and Cost/Weight
    - Quantify cost / value balance of Off-Road content
    - Identify / justify appropriate technologies

Thank you