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Intelligent Mobility: An Assessment of Past and Present UGV Concepts at DRDC Suffield

B. Beckman and D.M. Hanna
Defence R&D Canada – Suffield

C. Brosinsky
Providence One Inc.

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Author

B. Beckman

Approved by

D.M. Hanna

HTVSS

Approved for release by

R.G. Clewley

DRP Chair

Abstract

The Tactical Vehicle System Section (TVSS) of Defence R&D Canada – Suffield (DRDC Suffield) conducts research to exploit the potential of Unmanned Ground Vehicles (UGVs) for increasing soldier survivability and mobility. UGV mobility is one area of concern. Intelligent mobility describes the ability of an unmanned ground vehicle to traverse unstructured, obstacle-ridden terrain successfully with limited or less discriminating perception and simplified control. This paper provides an assessment of the intelligent mobility of an emerging concept compared to four previous UGV platforms developed for/by DRDC Suffield. It describes the SAAS (Solid Axle Ackerman Steered) UGV concept in terms of its hardware configuration, control hardware requirements, and attendant mobility performance. The SAAS will exhibit superior performance for UGV operations and roles.

Résumé

La Section des systèmes de véhicules tactiques (SSVT) de R & D pour la défense – Suffield (RDDC Suffield) conduit une recherche visant à exploiter le potentiel des véhicules terrestres sans pilote (VTSP) qui augmenterait la survivabilité et la mobilité des soldats. La mobilité de ces véhicules est un secteur préoccupant. La mobilité intelligente consiste en la capacité d'un véhicule terrestre sans pilote à traverser des terrains non structurés et garnis d'obstacles, avec une perception limitée ou moins sensible et une commande simplifiée. Cet article évalue la mobilité intelligente d'un concept émergent en le comparant à quatre plates-formes antécédentes de véhicules mises au point par le RDDC Suffield. Il décrit le concept du véhicule terrestre sans pilote à essieu directeur rigide en termes de configuration de la machine, de ses besoins en matériel de commande et de la performance en mobilité qui en résulte. L'essieu directeur rigide Ackerman fait preuve d'une performance supérieure au niveau des opérations et du rôle des véhicules terrestres sans pilote.

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Executive summary

One key research direction of the Defence R&D Canada – Suffield (DRDC Suffield) Tactical Vehicle System Section (TVSS) is to exploit the potential of Unmanned Ground Vehicles (UGVs) for increasing soldier survivability and mobility. Platform mobility is sometimes overlooked for UGV's even though mobility is an important factor in their success. Intelligent mobility describes the ability of an unmanned ground vehicle to traverse unstructured, obstacle-ridden terrain successfully with limited or less discriminating perception and simplified control.

One of the first vehicles modified and put into use by DRDC Suffield as an unmanned ground vehicle was the ARGO chassis produced by Ontario Drive and Gear. The ARGO benefited from a relatively low control complexity and a simplistic driveline. However, the desire to improve the mobility of the platform and, at the same time, reduce the control complexity (i.e. number of actuators and associated electronic hardware) led DRDC to develop the Enhanced Driveline ARGO (EDARGO). This modified ARGO, built upon the same basic platform, reduced the control complexity from four driving functions/actuators down to two and generally increased the vehicle mobility by using hydrostatic drive and bogey suspension. A follow-on vehicle development was an all electric drive 8x8, skid-steered platform similar to the ARGO chassis. This vehicle improved DRDC Suffield knowledge of electrical drive components and performance in the context of the existing configuration. All three of these configurations suffered from a poor ability to turn efficiently or smoothly on high traction surfaces as well as low driveline efficiency. The Articulated Navigation Testbed (ANT), a fourth UGV platform development, exhibited potentially very high mobility through its complex mechanical systems and articulated steering but was burdened by an associated high control complexity (many control actuators and electronic hardware required to control the many degrees of freedom associated with rotating hip joints of legs and articulation joints connecting body segments). Although this vehicle represented a significant improvement conceptually, it was not practical at a size and weight comparable to the other chassis' described above.

The Solid Axle Ackerman Steered (SAAS) UGV is an intelligent mobility concept possessing high intrinsic mobility with an attendant reduction of perception but with increased control requirements. It is a 4x4 configuration that utilizes a conventional mechanical automotive drive train for efficient propulsion with two Ackerman steered solid axles and long-travel suspensions for superior off-road and urban mobility as well as efficient and capable turning under all circumstances compared to each of the previous configurations.

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Sommaire

Une direction-clé de la recherche de la Section des systèmes de véhicules tactiques (SSVT) de R & D pour la défense – Suffield (RDDC Suffield) vise à exploiter le potentiel des véhicules terrestres sans pilote qui augmenterait la survivabilité et la mobilité des soldats. On ne tient pas toujours compte de la mobilité des plates-formes en ce qui concerne les VTSP bien que la mobilité soit un facteur important de réussite. La mobilité intelligente consiste en la capacité d'un véhicule terrestre sans pilote à traverser des terrains non structurés et garnis d'obstacles, avec une perception limitée ou moins sensible et une commande simplifiée.

Un des premiers véhicules modifiés et mis en service par RDDC Suffield, comme véhicule terrestre sans pilote, était le châssis de l'ARGO produit par Ontario Drive and Gear. L'ARGO avait l'avantage d'une commande relativement peu complexe et d'un train de transmission simpliste. Cependant, le désir d'améliorer la mobilité de la plate-forme et par la même occasion de réduire la complexité de la commande (par ex : le nombre d'actionneurs et du matériel électronique qui y est associé) a amené le RDDC à mettre au point L'ARGO à ligne de transmission améliorée (EDARGO). Cet ARGO modifié, construit sur la même plate-forme de base, a réduit la complexité de la commande de quatre à deux le nombre de fonctions/d'actionneurs et a généralement augmenté la mobilité du véhicule en utilisant l'entraînement hydrostatique et la suspension à bogie. Un suivi de mise au point du véhicule a résulté en une commande de pointage électrique 8x8, avec une plate-forme à direction préférentielle similaire au châssis de l'ARGO. Ce véhicule a amélioré les connaissances du RDDC Suffield au niveau des composants à entraînement électrique et de leur performance dans le contexte de la configuration existante. Chacune de ces trois configurations souffrait d'une faible capacité à tourner efficacement ou sans secousses sur des surfaces de grande traction et la transmission était peu efficace. Le banc d'essai articulé de navigation (ANT), une quatrième plate-forme de VTSP, a fait preuve que celui-ci possédait une très grande mobilité au moyen de systèmes mécaniques complexes et d'une direction par châssis articulé mais qu'elle avait l'inconvénient d'avoir en conséquence une commande très complexe (beaucoup de vérins de contrôle et de matériel électronique contrôlant les nombreux degrés de liberté dus aux articulations de la hanche des jambes et des autres articulations attachées aux segments du corps). Bien que le véhicule représente une amélioration importante au niveau du concept, sa taille et son poids ne sont pas pratiques si on le compare aux autres châssis décrits ci-dessus.

Le VTSP avec axe directeur rigide Ackerman est un concept de mobilité intelligente qui possède une grande mobilité intrinsèque accompagnée d'une réduction de la perception mais avec pour conséquence une augmentation des besoins au niveau de la commande. Il s'agit d'une configuration 4x4 qui, comparée à chacune des configurations précédentes, utilise une transmission mécanique automobile classique pour une propulsion efficace avec deux essieux directeurs rigides Ackerman ainsi qu'une suspension pour les longues distances produisant une mobilité supérieure urbaine et hors-route qui soit efficace. Il est aussi capable de tourner dans toutes les circonstances.

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Introduction

One key research direction of the Defence R&D Canada Suffield (DRDC Suffield) Tactical Vehicle Systems Section (TVSS) is to exploit the potential of Unmanned Ground Vehicles (UGVs) for increasing soldier survivability and mobility. The risk to, and workloads of, personnel can be reduced while simultaneously improving the efficiency of accomplishing existing tasks through the use of robotic systems. Platform mobility is sometimes overlooked even though mobility is an important factor in the success of UGV's. Intelligent mobility describes the inherent ability of a robotic vehicle, in this case an unmanned ground vehicle, to negotiate an unstructured environment successfully with low levels of perception and control.

One of the first vehicles modified and put into use by DRDC Suffield as an unmanned ground vehicle was the ARGO chassis produced by Ontario Drive and Gear. The ARGO benefited from a relatively low control complexity and a simplistic driveline. However, the desire to improve the mobility of the platform and, at the same time, reduce the control complexity (i.e. number of actuators and associated electronic hardware) led DRDC to develop the Enhanced Driveline ARGO (EDARGO). This modified ARGO, built upon the same basic platform, reduced the control complexity from five driving functions/actuators down to two and generally increased the vehicle mobility by using hydrostatic drive and bogey suspension. A follow-on vehicle development was an all electric drive 8x8, skid-steered platform similar to the ARGO chassis. This vehicle improved DRDC Suffield knowledge of electrical drive components and performance in the context of the existing configuration. All three of these configurations suffered from a poor ability to turn efficiently or smoothly on high traction surfaces as well as low driveline efficiency compared to mechanical drive systems. The Articulated Navigation Testbed (ANT), a fourth UGV platform development, exhibited potentially very high mobility through its complex mechanical systems and articulated steering but was burdened by an associated high control complexity (many control actuators and electronic hardware required to control the many degrees of freedom associated with rotating hip joints for legs and articulation joints connecting body segments). Although this vehicle represented a significant improvement conceptually, it was not practical at a size and weight comparable to the other chassis' described above.

This paper compares the intelligent mobility of the UGV platforms described above to the mobility and control benefits of the next, in terms of a logical design progression, 'intelligent mobility' UGV concept. The Solid Axle Ackerman Steered (SAAS) vehicle is a 4x4 configuration that utilizes a conventional mechanical automotive drive train for efficient propulsion with two Ackerman steered solid axles for efficient and capable turning under all circumstances. The mobility benefits and basic control hardware requirements of this configuration will be compared to past research vehicles.

Measures of Performance – Mobility

Mobility is a term used to describe a vehicle's ability to traverse unstructured and challenging terrains. To better understand mobility, it is helpful to reduce the term to easily definable components. The Tactical Vehicle Systems Section of DRDC Suffield uses the following terminology to describe the technical scope of the mobility problem, affectionately called the 'ilities' of mobility:

- *Agility* describes the acceleration and deceleration performance of a vehicle and is related to the vehicle power to weight ratio and braking capabilities.
- *Stability* refers to the ability of the vehicle to keep the rubber side down, whether in high speed turning manoeuvres or side slope operations.
- *Maneuverability* describes the ability to avoid obstacles and vegetation and is a function of vehicle geometry and its turning capability.
- *Trafficability* refers to vehicle performance in soft or deformable soil conditions and is a function of floatation and traction.
- *Ride Quality* describes the shock and vibration performance of the vehicle when operating over rough ground.
- *In/egressability* describes how well a vehicle is able to negotiate positive and negative linear features and slopes.

ARGO Unmanned Vehicle

ARGO General Description

The ARGO vehicle is a standard Ontario Drive and Gear chassis with modifications to the braking system in order to permit remote vehicle turning (via the application of brakes). To complete the remote capability, the vehicle was outfitted with throttle control as well as directional and speed range gear selection. The vehicle was designed to be either driven remotely or with minor manipulation by a person.

The ARGO vehicle is an eight wheel drive vehicle with a rigid chassis and extensive payload volume. The tires provide the entirety of suspension and may be adapted for use with a track laying system to improve floatation. Each side of the vehicle is equipped with a set of four wheels that are linked together via a series of heavy drive chains. Each side of the vehicle is driven from a geared transfer case that is powered by a gasoline engine via a variable speed belt drive. The transfer case drives a prop shaft to each side of the vehicle and provides the locomotion force. Turning is accomplished by the hydraulic application of disk brakes on the prop shaft which stops the rotation of the shaft on either side. These disk brakes are manipulated by a set of discrete hydraulic valves. Throttle position and control is provided via a servomotor. An electrical linear actuator provides gear selection. The system is strictly mechanical and therefore quite power efficient, exhibiting good locomotive effort on a variety of soils.

The ARGO requires four actuators and associated electronic control hardware in order to achieve unmanned control of the basic vehicle driving functions (throttle, left brake, right brake, gear shift).

ARGO Mobility

- **Agility** -The ARGO chassis has excellent acceleration due to the ratio of vehicle weight and available power. The vehicle is not geared for high speed and is therefore well suited to the relatively low speed required for UGVs. With the vehicle being all wheel drive, the acceleration is consistent and smooth. The decelerating performance is largely a factor of the rolling resistance, which is high for this vehicle, and it slows quickly once the power is removed. Braking can be selectively applied if necessary; in fact, anti lock braking is available through the control system.

- **Stability** – The ARGO chassis, with its low centre of gravity and essentially rigid chassis has good stability in slope climbing or side slope operations. The low vehicle speed of which it is capable renders it stable in dynamic manoeuvres as well.

- **Maneuverability** - The frequency of braking application determines the vehicles turning radius. The resulting turning motion is somewhat jerky due to the rapid application of the brakes during a turn. Proportional control of the brakes is not recommended (i.e. slipping the brakes to provide a smoother turning radius) due to the extreme heat build up and the resultant brake fade of the system. The lateral acceleration input to the chassis from turning has shown itself to be modestly problematic for camera and sensor systems.

- **Trafficability** – This vehicle exhibits good straight line soft soil mobility because of its high floatation tires or tracks. The vehicle demonstrates very marginal soft soil turning performance due to soil excavation on the driven side attempting to turn the vehicle against a braked other side. The end result is that available turning radii in soft soil is necessarily larger than desirable.

- **In/egressability** - The ARGO has a rigid chassis and the suspension is provided entirely by the low inflation pressure tires. The vehicle bridges small linear features well because of the rigid chassis. The all wheel drive helps to make the vehicle quite capable of driving over terrain irregularities despite the dramatic body excursions. Approach and departure angles are reasonable. The ARGO is limited in its slope ability only by available power, tire selection and gross vehicle weight. The ARGO is considered suitably powered to handle typical slopes.

- **Ride Quality** - The tires provide the entirety of the suspension through low inflation pressure compliance. For most applications this is suitable but some linear features such as step functions provide a greater challenge for the vehicle in providing a smooth ride for the sensors and camera systems.

EDARGO Unmanned Vehicle

EDARGO General Description

The EDARGO is a highly modified ARGO vehicle with the major modification being the installation of a hydrostatic transmission in place of the typical skid steer transfer case drive. The motivation behind this modification was to create a driveline that was very simple to control and had an abundance of mobility capability. In this version of the vehicle, a tandem hydraulic pump was driven by a fixed ratio belt drive from the engine and controlled by a custom swash plate controller. The swash plate controller responds to the operator input by setting the displacement on the pump and directing the flow to a pair of hydraulic motors, one driving each side of the vehicle. As with the ARGO chassis, the wheels are locked together by a series of chains driving their pinion shafts. The swash plate controller independently controls the speed and direction of each side of the vehicle.

The EDARGO requires only two actuators and associated electronic control hardware in order to achieve unmanned control of the same basic vehicle driving functions as ARGO (wheel speed left side, wheel speed right side – throttle is held constant).

EDARGO Mobility

- Agility - The EDARGO has excellent acceleration characteristics due to the high torque hydraulic motors that drive the wheel sets. The hydraulic motors have an unusually high efficiency (for hydraulics) at low speed. They also have a high torque range and wide speed range due to the input flow from the variable displacement pump. (The lack of hydraulic efficiency at low speed and high torque conditions has been overlooked by many that have attempted this configuration). The deceleration performance is also very good and quite controllable due to the non compressible fluid of hydraulic systems. Deceleration performance can be compromised under certain circumstances by cavitations in the motors (i.e. the motor essentially freewheels when the vehicle is slowing down).

- Stability – The EDARGO, like the ARGO chassis, has good stability as a result of its low centre of gravity and essentially rigid chassis. Although it is capable of higher vehicle speeds and accelerations than the ARGo, it is still stable in dynamic manoeuvres.

- Maneuverability - The hydrostatic transmission in EDARGO is conducive to excellent turning capability ranging from pivot turns (i.e. zero radius turns) to any radius turn desired. The mechanical nature of the system means that the power available to the wheels is consistent. Although the turning performance is good, there remains some level of lateral tire scrubbing due to the fixed nature of the footing elements and therefore requires considerably more power to negotiate turns than is required for Ackerman or articulated steering vehicles.

- Trafficability – The soft soil performance of EDARGO is acceptable due to floatation of the footing elements through either a combination of number of tires, size of tires, or the option of tracks. The footing elements of EDARGO can be configured for 4x4, 6x6, or 8x8 with bogey suspension. In the 4x4 configuration, the footing elements can be upsized in diameter and/or width to provide additional floatation. Further, tracks can be installed on any configuration of this vehicle if a tracked system is preferred. The 8x8 configuration requires the most power to turn due to the increased turning moment. The smooth nature of differential wheel speed turning, as opposed to turning accomplished by braking as with ARGO, essentially eliminates footing element excavation during turning maneuvers.

- In/egressability - Depending on the footing element configuration, the EDARGO performs well when passing over linear features due, in large measure, to the combination of low inflation pressure tires (which absorb shock) and the movement of the footing elements provided by the bogey style suspension. The suspension permits the vehicle to maintain equal footing element contact on terrain while providing an improved ability to bridge linear features. This configuration is capable of approach and departure angles that extreme with the ability to climb vertical surfaces if sufficient traction is available. This capability is essentially a function of the bogey suspension, weight and available power. Being a hydro-mechanical system, the performance is consistent over time due to the consistent delivery of power to the wheels.

- Ride Quality – Linear body excursions are greatly reduced compared to a standard ARGO due to the suspension of the bogey system. Body excursion is roughly half of the tire excursion over an obstacle. The low inflation pressure tires, which absorb both low frequency shocks and high frequency vibrations, in combination with the bogey suspension provide a ride quality that is suitable for unmanned usage with cameras and sensor systems.

Kodiak Electric Drive Unmanned Vehicle

Kodiak General Description

The Kodiak platform was intended to be a direct replacement for the EDARGO 8x8. The EDARGO provided for a differential wheel speed turning capability and thus simpler more accurate control as well as the bogey style suspension. The Kodiak configuration kept the differential wheel speed turning ability and added ground clearance by including a vertical depth to the bogeys. The drive system also utilized belt drives rather than chain drives in an effort to reduce the maintenance required on the mechanical systems.

The drive line is a 120 volt DC electric drive system with an electric motor driving each side of the vehicle via a gear reduction (50:1). The gear reduction is required to permit the electric motors to operate much of the time in the 3000 - 4000 RPM range where they are most efficient. The efficiency map for these motors indicates they are very inefficient at lower RPMs. The motors drive a long toothed drive belt that in turn drives a pair of shafts that support the bogey drive components and provide the locomotive force for the wheel drives. Inside the bogey there is an additional belt drive system to turn the pair of wheels attached to it.

A bank of ten gel cell Optima batteries provide energy storage for the Kodiak and charging is accomplished by a stationary 'smart' charger capable of replenishing the batteries in approximately 2 hours. Typical run times for the Kodiak were approximately 30 minutes regardless of speed and maneuvers performed. The drive motors themselves are rated at 20 HP (15KW) at full current draw. In keeping with the current driveline power rating, they are limited to 10 HP (7.5 KW) max.

The Kodiak, like the EDARGO, requires only two actuators and associated electronic control hardware in order to achieve unmanned control of the same basic vehicle driving functions as ARGO (wheel speed left side, wheel speed right side – no throttling of an IC engine is required).

Kodiak Mobility

- **Agility** – The Kodiak has very impressive acceleration at the beginning of the battery discharge cycle but the performance declines continually through the cycle. The deceleration performance was never implemented but can be significant as the motor drive system and controller are capable of regenerative braking. This means that the vehicle momentum can be converted into electrical energy and the vehicle can be made to decelerate rapidly. The Kodiak had no other braking capability other than rolling resistance and a settable parking brake to prevent unintentional rolling of the vehicle.

- **Stability** – The Kodiak chassis, despite having more ground clearance that the previous two configurations, possesses good stability because it maintains a relatively low centre of gravity. Since it is only capable of modest vehicles speeds, it remains stable in dynamic manoeuvres.

- **Maneuverability** - The Kodiak configuration is very capable of turning through differential wheel speed on moderate traction surfaces and could effectively be commanded to execute a desired turning radius right down to a minimum of a 'turn in place' capability. Realistically, however, the maneuverability on high traction surfaces was limited by the available power.

- **Trafficability** – The configuration of the Kodiak is well suited to moving though soft soils due to the high flotation footing elements and the high ground clearance which reduces the amount of belly drag on the chassis. As before, limitations in soft soils are noted both in turning and agility due to the available battery power.

- **In/egressability** – The Kodiak, with its rotating bogey suspension and high ground clearance, does very well when negotiating linear features. The performance continually diminishes over time because of the limited power available from the batteries. The approach and departure angles of the Kodiak are such that it is possible to climb vertical obstacles if power permits. There is no impediment to the slope capability of the Kodiak, provided that sufficient battery power is available.

- **Ride Quality** – The combination of low inflation pressure tires (high frequency damping) and the bogey suspension (low frequency damping) provide a very smooth ride for the vehicle. The bogey suspension absorbs much of the linear travel associated with hitting obstacles and the tires absorb much of the higher frequency vibration from the road contact. The tires also limit the shock the entire system feels by complying with the surface of an obstacle. Because Kodiak is electric, there is no high frequency vibration induced by a reciprocating engine.

Articulation Navigational Testbed (ANT) Unmanned Vehicle

ANT General Description

High generic mobility is the basis for the highly conformal nature of the ANT. The ANT configuration can raise or lower its center of gravity as well as increase or decrease its ground clearance on demand. Thus, when the vehicle is off-road, it ia able to assume a vertical leg stance and have increased ground clearance beyond that of most manned trucks. When on-road, it can assume a flattened leg profile and have a very low center of gravity. The ANT was developed with the following design cues that were determined to be effective solutions to general mobility.

The ANT concept was thought to possess superior off-road mobility compared to conventional vehicles. The concept vehicle comprises multiple body modules and was steered by articulation. Each module contained a rigid structure to which member systems of the module are attached: two legs connected to the structure by rotating hip joints, and wheels mounted to the output shaft of a hydraulic wheel motor at the lower ends of each of the legs. The vehicle moves by either turning the wheels, rotating the legs to which the wheels are attached, or a combination of both. A typical high mobility configuration is a three module platform, although it may be extended to four, five or more depending on specific mission requirements.

The articulation joint between modules has one degree of freedom. It is capable of yaw motion, which is accomplished by linear actuators. The roll and pitch compliance was considered to be unnecessary. One principal motivation for using legs was the ability to follow longitudinal and lateral elevations changes while maintaining a relatively flat body geometry.

The vehicle employs multi-body articulation. Each chassis module follows the arc traveled by the preceding module and may exactly follow the track of the preceding module if leg geometry is selected appropriately. Thus, in terrain with high obstacle density, and particularly in vegetation, the articulated steering creates some inherent obstacle avoidance for trailing modules.

The control requirements of the ANT vary according to its configuration. The two module 4x4 configuration requires only two actuators and associated electronic control hardware in order to achieve unmanned control of the same basic vehicle driving functions as ARGO (namely, wheel speeds and articulation joint angle – throttle is again held constant). Correspondingly, the three module 6x6 configuration requires three actuators (wheel speed and two articulation joint angles) to accomplish basic driving. Clearly, however, the control complexity increases substantially as the many additional degrees of freedom are exercised.

ANT Mobility

- **Agility** - ANT incorporated high torque low speed hydraulic motors at the end of each leg. These motors were controlled in both speed and direction by a pair of linear actuators on the hydraulic pump thereby greatly simplifying the infrastructure and control code normally required for these primary functions.

- **Stability** – With the capability of adjusting (lowering) the height of its centre of gravity in real time, and of leveling the body attitude in side slope by independent operation of legs, the ANT configuration possesses superior stability compared to all other configurations. As with any articulated steering configuration, dynamic stability at high speed is an issue for ANT.

- **Maneuverability** - The body articulation permits power efficient, tight radius turning of the system. An additional benefit is a true tracking capability where each successive tire follows in the rut created by the leading tire. True tracking also provides a retro-traverse capability that permits the extraction of a vehicle that is immobilized due to a nose-in failure. By simply 'rewinding' the steering commands that produced the failure, the vehicle can extract itself. Maneuverability was further enhanced by the ability to adjust leg positions to achieve dramatic changes in wheelbase so as to alter stability margins or turning radii.

- **Trafficability** - The footing elements and even the legs of ANT are modular to permit the tailoring of tires (soft soil floatation), leg length, or additional implements (tracks etc) to match the expected terrain conditions. More importantly, the ANT is intentionally designed to be lightest at the front and progressively heavier towards the rear modules allowing a degree of progressive loading of soft soils; in effect, preconditioning the terrain. Attaching additional body units to the system also has a decided mobility advantage when crossing gaps.

- **In/egressability** - As previously stated, this is the most difficult mobility challenge for most vehicles. However, the ANT configuration has the ability to climb onto obstacles, to push itself over obstacles by changing the vehicle's approach and departure angles, and to bridge over negative linear features. Obviously, the dramatic range of ground clearance afforded by the leg position will permit the conquering of many obstacles previously impossible for vehicles of its size. The hydraulic motors chosen for ANT exhibit high volumetric efficiency and are well suited to moving the vehicle up steep grades and delivering high torque at low speeds. In addition, the adjustable legs of the vehicle permit sideslope leveling of the vehicle body as well as pitch leveling for improved ingress/egress performance.

- **Ride Quality** - ANT's low inflation pressure tires are compliant and act as a first order intrinsic protection against shock and vibration. The rapid movement of the legs at low vehicle speeds provide a degree of active suspension for the vehicle.

Solid Axle Ackerman Steered (SAAS) Unmanned Vehicle

SAAS General Description

Achieving relatively high intrinsic mobility with relatively low control complexity was the basis for the SAAS vehicle. The SAAS vehicle concept is a four wheel drive, solid (live) axle, four wheel Ackerman steered unmanned vehicle that utilizes long travel, four link suspensions to locate the axles and a high gear reduction (~200:1) mechanical drive to achieve efficiency, mobility, and controllability. The four wheel drive capability will provide excellent smooth acceleration due to the low gear reduction. The vehicle will be equipped with high floatation tires that will make it excellent for soft soil mobility and conforming to obstacles. The vehicle can be utilized in either two wheel or four wheel Ackerman steering modes. This allows for high maneuverability and low rolling resistance while turning. The system allows for a tight turning radius in four wheel mode at low speeds and single Ackerman at higher speeds to prevent rollovers. The four wheel steering will also provide a retro-traverse capability that permits the extraction of an unmanned vehicle that is immobilized due to a nose-in failure simply by 'rewinding' the steering commands that produced the failure. The suspension of the vehicle is based on high mobility four link suspensions and the ladder chassis arrangement commonly found in monster trucks. The vehicle is comprised of two solid axles attached to a four bar suspension system. The large articulation of the axle provides the vehicle with the ability to cross large obstacles. The SAAS vehicle concept is thought to possess superior off-road controllable mobility compared to conventional vehicles.

The control requirements for SAAS to accomplish basic driving functions dictate the need for four actuators and associated electronic control (engine speed, gear selection, braking, and front axle steering). However, in order to achieve full functionality of this configuration, four additional actuators are required (namely, rear axle steering, Klune gear reduction selection, transfer case high/low range selection, and locking differential selection). Although this is a lower control requirement than for complex multi-unit ANT control, it is clearly a more demanding requirement than for a basic two-unit ANT configuration or any of the other configurations discussed above.

Solid Axle Ackerman Steered Mobility

- **Agility** – The SAAS will have excellent acceleration due to its high power to weight ratio. The vehicle was also geared for very slow speed that is essential for UGV operations. The vehicle will also be all wheel drive which will provide smooth and consistent acceleration. The deceleration performance will be from the marginal rolling resistance of the geared assembly and from the disc brakes on each wheel.

- **Stability** – Although the SAAS will have a much higher ground clearance than the other configurations, it also has a considerably wider track width and longer wheelbase. Therefore, it will have side slope stability performance comparable to the other platforms. As a result of compliant suspension elements, the SAAS may encounter dynamic stability problems when operating at the significantly higher operating speeds of which it is capable.

- **Maneuverability** - The SAAS will operate in either two wheel or four wheel Ackerman steering modes. The four wheel steering mode will provide a tight turning radius at lower speeds. Ackerman linkages allow the inside wheel to turn at a greater arc than the outside wheel thus preventing slippage. The tight turning radius will be defined by the vehicle geometry. When determining the ICC (Instantaneous Center of Curvature), the distance between the axles and the steering wheel angles need to be known to find the radius of curvature. The two wheel configuration will be used at higher speed to prevent rollovers. The four wheel steering will also provide a retro-traverse capability that permits the extraction of a vehicle that is immobilized due to a nose-in failure. By simply 'rewinding' the steering commands that produced the failure, the vehicle can extract itself.

- **Trafficability** – The SAAS vehicle will be equipped with high flotation tires and locking differentials that will deliver excellent straight line, soft soil mobility. The nature of the four wheel Ackerman steering system will provide good soft soil performance due to the fact that there will be minimal soil excavation of the tires during turns. The geometry of a four wheel Ackerman steered vehicle allows the turning radii in soft soil to be the same as that for regular conditions.

- **In/egressability** – The SAAS vehicle with its ladder chassis, four bar linkage, locking differentials, and solid axle suspension will provide for excellent negotiation of linear features. The high diameter, low inflation pressure tires and the highly compliant suspension provide the vehicle with high ground clearance and the ability to operate in off-camber situations that are beneficial to traversing over and conforming to obstacles. The unique configuration of the vehicle allows it to climb extreme, irregular slopes as well as descend the same type of terrain. The low gear ratio of the vehicle maximizes torque for moving the vehicle up steep grades.

- **Ride Quality** – The low tire inflation pressure has the ability to absorb low frequency shocks and high frequency vibrations. The compliant four bar linkage suspension system will absorb much of the linear travel associated with hitting obstacles.

Summary

The principal objective was to demonstrate that an additional UGV concept at Defence R&D Canada – Suffield would benefit from the experience learned of the previous platforms deficiencies and advancements.

The ARGO platform was the first attempt at unmanned vehicle mobility. It provided a solid platform that DRDC used to begin development and demonstration of relatively low control complexity by working solely with throttle control, direction control and speed range gear selection. The relatively low complexity turning functions combined with the ease of using a stable development platform provided DRDC with a building block for future developments. The lack of suspension and marginal soft soil performance were the motivating force behind the development of the EDARGO.

The EDARGO uses the lessons learned from the ARGO which is a similar platform but incorporates more capable and simpler controls. The EDARGO has proven to be a very reliable performer and considerable development has gone into the system to improve its capabilities. The EDARGO uses a hydrostatic transmission in place of the typical skid steer transfer case. The vehicle exhibits very good turning characteristics from the hydrostatic drive to achieve any desired turning radius. The bogey suspension system provided better linear feature crossing, slope climbing characteristics and ride quality. The vehicle remains a useful platform for Unmanned Ground Vehicle (UGV) technology development to this day due to its adaptability and available power.

The Kodiak was developed to provide an understanding into electrical drive technology with a chassis similar to EDARGO. The vehicle has similar mobility characteristics to the EDARGO but has the added benefit of simpler controls due to the use of electric motors. However, the relatively small duty cycle due to the power density of the batteries makes the platform task specific. It is very useful for demonstrating strap on technologies such as camera and sensors because of its geometry and utility. It has also been useful in determining the technical issues of using electric drive technology. It was proven that the electrical drive technology does not have a lower maintenance cycle than its mechanical counterpart.

High generic mobility is the basis for the highly conformal nature of the Articulated Navigation Testbed (ANT). The ANT concept was thought to possess superior off-road mobility compared to conventional vehicles. This concept comprises multiple body modules and is steered by articulation. Each module contains a rigid structure to which member systems of the module are attached; two legs connected to the structure by rotating hip joints, and wheels mounted to the output shaft of a hydraulic wheel motor at the lower ends of each of the legs. The vehicle moves by either turning the wheels, rotating the legs to which the wheels are attached, or a combination of both. However, the power density of the ANT is marginal at this scale and its large number of degrees of freedom would require extensive programming to control it in a suitable manner. This vehicle is an example of an outstanding concept that would benefit from a more thorough scaling study.

The SAAS vehicle benefits from all of the previously built platforms. The steering lessons learned from the ARGO were that true skid steered vehicles cause side excavation; from EDARGO and Kodiak, that differential steered vehicles are better but require considerable power to turn. The ANT provided articulation for steering which lowers the amount of power required to turn the vehicle but a zero turning radius can not be achieved. Therefore, the decision was made to take advantage of the ease in turning along with the small turning radius of a four wheel Ackerman vehicle. The power choice of a four wheel drive mechanical system was arrived at by comparing the performance of previous platforms. The ARGO used an all wheel drive mechanical drive system that provided excellent efficiency through the power train. The hydrostatic drive EDARGO, electric drive Kodiak and hydraulic wheel motor of the ANT are all less efficient than a mechanical system. Therefore, the SAAS vehicle will utilize an all wheel drive mechanical system with very low gear reduction to keep power efficiency as high as possible. All of the vehicles described above were equipped with high floatation tires that made them excellent for straight line soft soil mobility. Each vehicle experienced different turning performance in soft soils due to the vehicle configuration. The SAAS vehicle will be equipped with extremely high flotation tires and will possess a suitable vehicle configuration for all soft soil mobility functions.

The suspension, in terms of obstacle crossing, for each vehicle is considerably different from the ARGO which had virtually no suspension other than the air in the tires. The EDARGO and Kodiak have more suspension with a bogey type arrangement allowing equal footing pressure on each tire regardless of terrain. The ANT has the highest potential of crossing obstacles with virtually no passive suspension, only the precise placement of the footing elements. The SAAS vehicle will be equipped with high mobility four link suspension and a ladder chassis arrangement. The vehicle is comprised of two solid axles attached to a four bar suspension system. This arrangement provides the vehicle with the ability to cross large obstacles due to the large relative articulation of the two axles. The SAAS vehicle concept possesses superior off-road mobility compared to other unmanned vehicles.

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The Tactical Vehicle System Section (TVSS) of Defence R&D Canada – Suffield (DRDC Suffield) conducts research to exploit the potential of Unmanned Ground Vehicles (UGVs) for increasing soldier survivability and mobility. UGV mobility is one area of concern. Intelligent mobility describes the ability of an unmanned ground vehicle to traverse unstructured, obstacle-ridden terrain successfully with limited or less discriminating perception and simplified control. This paper provides an assessment of the intelligent mobility of an emerging concept compared to four previous UGV platforms developed for/by DRDC Suffield. It describes the SAAS (Solid Axle Ackerman Steered) UGV concept in terms of its hardware configuration, control hardware requirements, and attendant mobility performance. The SAAS will exhibit superior performance for UGV operations and roles.

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