Enclosing and Mounting an Electronic Component on Articulated Haulers

A proposition on how to protect, and where to place, an intelligent node on the environmentally harsh exterior of construction equipment with respect to multiple parameters

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Abstract

As is the case with many other manufacturers of vehicles, Volvo Construction Equipment has a constantly increasing amount of electric and electronic equipment in their articulated haulers. These are of great use in modern machines, bringing functions, and safety that were not possible before, but they also bring more cables to handle.

In the case of the articulated haulers a quite thick cable harness of about 15 meters in length reaches from the driver’s cabin in the front to the components in the far back end of the vehicle. This is not only a lot of long cables to handle both during assembly and service, but the nature of signals traveling in cables is that the voltage gets weaker with distance. This phenomenon has to be accounted for by measuring devices dependent on the voltage.

It has been suggested that a device referred to as an intelligent node, or ICCS-module, which communicates digitally via CAN could be installed in the back of the articulated haulers. This module would be independent of the mentioned drop in voltage. The ICCS-module will be receiving a small bundle of cables being routed from the driver’s cabin. From it cables would go out to a majority of the components in its vicinity. The components connected to the node would not need to have any other cables.

This thesis is focused on the mechanical aspects of installing this ICCS-module. Having electric and electronic equipment on construction vehicles is a challenge when it comes to protecting the device from the harsh environment that is the hauler’s exterior. It will have to withstand being immersed in water for long periods of time, greatly varying temperatures, vibrations and shocks as well as being hit by projectiles. The placement as well as the design of the enclosure should be chosen with respect to both the device’s length of life and how well it fulfils its intended role and achieves the expected results.

To produce an enclosure and find a placement aiming to satisfy these conditions, a traditional product development process were executed. The articulated haulers as well as relevant literature were researched. Concepts were generated and evaluated by both the author and by employees at Volvo Construction Equipment until a final concept for the enclosure and placement were found. The enclosure were then designed in detail specifying the material, manufacturing techniques, controlled for thermodynamic circumstances, modelled in Catia V5 and controlled for vibrations. It was concluded that the enclosure should be able protect the ICCS-module after some more development and that the placement and cable routing results in a much shorter total cable length.
Preface

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# Nomenclature

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<th>Description</th>
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<tr>
<td>ART</td>
<td>Articulated hauler</td>
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<tr>
<td>CAD</td>
<td>Computer-Aided Design</td>
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<tr>
<td>CAN</td>
<td>Controller Area Network</td>
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<tr>
<td>Catia</td>
<td>CAD-software produced by Dassault systems</td>
</tr>
<tr>
<td>E&amp;E</td>
<td>Electrical and Electronic systems</td>
</tr>
<tr>
<td>ECU</td>
<td>Electronic Control Unit</td>
</tr>
<tr>
<td>Enclosure</td>
<td>The shell, or box, containing the ICCS-module</td>
</tr>
<tr>
<td>ICCS-module</td>
<td>The specific intelligent node from Würth Elektronik</td>
</tr>
<tr>
<td>VCE</td>
<td>Volvo Construction Equipment, Volvo CE, Volvo</td>
</tr>
<tr>
<td>WLO</td>
<td>Wheel loader</td>
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1 Introduction

In this chapter the grounds upon which the present thesis is built will be presented. This includes background, the problem at hand, what the thesis aims to result in as well as the limitations the author will been working with throughout the process.

The technical development of the machines at Volvo Construction Equipment (VCE) is ever ongoing. With an increasing amount of electrical and electronic systems (E&E) in every generation the installations of the cables belonging to these are becoming more and more demanding. This study will be looking into the possibility of using intelligent nodes to replace part of the cables between the E&E components and their respective Electronic Control Units (ECU), actuators and switches to eliminate problems in the above mentioned areas. A specific case will be studied in this thesis however, where the voltage drop between the back of the articulated haulers (ART) and the driver’s cabin is to be lowered with the help of a module. This drop occurs because of long cables and presents a disturbance for the load measuring sensors situated at the wheel axles.

1.1 Background

Volvo Construction Equipment has been developing construction machines since 1832 and is the oldest still going industrial company within this area. VCE is also the largest manufacturer of wheel loaders (WLO) and articulated haulers in the world, machines which are developed in Eskilstuna and produced at different locations in Sweden. (Volvo, 2016)

As the ARTs are developed the E&E-system becomes bigger, making it more complicated to realise new functions. In most cases in today’s machines the E&E equipment in the ART is connected to an ECU, switch or actuator via a traditional cable. (Volvo, 2016) This means that for each new function, more cables are added, something that can be unpractical during design, assembly, and service, among others. Another concern is that the length of the cables routed between the ECUs in the driver’s cab and the back of the ART is affecting the signal, distorting values received from sensors such as the load measuring devices at the back axels. These distortions are being compensated for today, but a solution that solves the problem at its root is preferred.

In private vehicles and trucks modules have been used for communication between E&E components for a long time (National Instruments, 2016). Modules are in essence small computers that can both transmit and receive signals in a network. Several E&E functions can be connected to a node which then will take care of the communication with ECUs and other nodes. The wiring between the functions and the ECUs will for the most part become digital, meaning that cable length will be less of a problem, and that the number of cables becomes less dependent on the number of E&E functions.

VCE has begun looking into using modules ought prior studies. A master’s project performed at VCE was studying the possibility of installing an intelligent node in a WLO’s cabin mainly to reduce the number of electrical cables between the ECU and the A-pillar. The project arrived at the conclusion that modules could serve as a useful tool
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to reduce the number of cables, but also to cut time in the assembly, and making service/maintenance in the cab easier. (Krainer, 2016)

1.2 Problem description

The use of E&E-systems is increasing in Volvo’s articulated haulers and wheel loaders and the number of electrical cables is becoming very large. Additionally, as more advanced functions are added the traditional cables are proving impractical. One case of this has appeared in the ART where sensors measuring the weight of the load in the bucket require compensation for the cable length. The voltage drop occurring when the signal travels through the exceptionally long cables (around 15 metres) going from the sensors in the ART’s suspension to the controllers in the ECU in the driver’s cabin is affecting the measuring result since it is based upon the resistance in the sensors. As a countermeasure an offset is added to the signal which needs to be calibrated for each vehicle type due to differences in cable lengths. Service, manufacturing and assembly becoming more complicated than necessary are examples of other complications occurring because of the massive wiring.

An intelligent node communicates digitally, and is therefore not as sensitive to cable length. Leaving the communication between the sensors and the ECU to a module could therefore be one solution to the voltage drop problem – with added benefits for other components. However, there are a few obstacles to get around. One problem that will occur is that the node is going to be exposed to a lot of water, mud, vibrations and crushing forces, meaning that an enclosure has to be able to keep the node safe from all of these. Installing these nodes also present new expenses, for one, the node itself is fairly expensive (ca. 50 Euros). Also, implementing it could mean extensive changes in the assembly and production.

1.3 Purpose and goal

The purpose of this thesis is to deliver knowledge to VCE about the possibilities concerning intelligent nodes which can be used in coming updates of their construction equipment.

The goal is to present a solution for how and Intelligent node can be installed in such a way that it will live up to the durability requirements and deliver the expected advantages, while avoiding being overly costly. If this goal is reached, the thesis is expected to be able to answer the following questions:

- Where should an Intelligent node be installed and how should it be protected from damage?
- How should the new E&E-system be constructed so that the lengths of the cables between the components and the node are minimised?
- What components should/should not be connected to the node?
1.4 Deliverables

- CAD-models of node placement and enclosure.
- Report on placement of the node and how the shell will work, describing what prototypes and ideas that have been dealt with.
- A basis that VCE can use when deciding whether the implementation of this node is motivated.

1.5 Delimitations

These delimitations are partly to keep the project within a reasonable scope, and partly to fulfil the wishes of VCE. Motivations are provided where it is deemed necessary.

- Functions that are critical for safety, e.g. the parking brake, will not be connected to the node.
- Although the solution will be kept as general as possible only ARTs in the latest generations (F, G and H) will be studied. The fully suspended models (FS) will only be considered to a limited extent as they are deemed to differ too much from the common models. Especially since it does not use load cells.
- Studies of the E&E-system will only concern the wiring harness and equipment in the back of the ART since other areas are not relevant to the present node.
- The node is assumed to work with the existing equipment.
- Electromagnetic capability (EMC) is not taken into consideration, since it is deemed that it would make the present project too large.
- Video, audio, radio, and high current signals cannot be transferred through the specified node.
- All of VCE’s technical requirements will not be fulfilled.
2 Methodology

In this chapter the plan for how the project will be performed is presented. This includes what activities will happen, in what order and how the project will benefit from them.

The project will be conducted by going through four phases which are partly present in all product development projects. The methods used during each phase are taken from various authorities in the field, such as Karl T. Ulrich and Steven D. Eppinger or David G. Ullman. An illustration of the general model can be seen in Figure 1 above which has been strongly inspired by Ulrich and Eppinger (2012). The main idea is that a product development process starts with a large amount of concepts which will be narrowed down as the project proceeds. Most of the theory and data needed for the project will be collected and documented during phase 0. Early concepts for the product will be generated in fairly great numbers during phase 1. During phase 2 these will be evaluated and reduced down to a number of candidate concepts which will be reviewed, modified and then once again evaluated and reduced until only one final concept remains. This concept will enter phase 3 and be designed in detail.

Some consideration for the products manufacturing methods will be taken during the detail design. This is, as is evident, not a complete development process. A whole process would continue into phases where tests were conducted, prototypes built and evaluated and - finally – the product could enter production. However, the time frame of this thesis limits the process to the four mentioned stages.
2.1 Phase 0: Theory and requirements

Essentially, this phase can be divided into two parts: collecting information needed to perform the project and defining the requirements of the end product. The task at hand will be analysed in deep through interviews, observations, visits to the production plant, reading up on technical information, etc. Each of the tools used during this phase are presented below.

2.1.1 Literature review

Literature reviews are a useful method for gaining knowledge in areas of interest during projects. They are good for creating a solid ground for arguments made and broadening the solution space. They can consist of either pure summaries or they can be used to fuel a discussion from which the author can derive their own conclusions. It is important to relate it to the work at hand. (UNC, 2016)

2.1.2 Interviews

Interviews with the assembly personnel and engineers working with the product at hand are a valuable source of input. Taking part of their experiences and knowledge concerning service, assembly, usage, etc. is a much more effective way of gaining information than coming to the same conclusions by observing and analysing the product. (Ryen, 2004)

Interviews are commonly separated into structured, semi-structured and non-structured interviews. In short, structured interviews are performed according to a manuscript; the questions, their order and their formulation are set beforehand and it is not allowed to add or remove anything. Non-structured interviews are conversations with a predefined subject, more or less. (Ryen, 2004) Semi-structured interviews are somewhere in between the previous two; questions are defined beforehand, but when and how these are asked is subject to change, and venturing into discussions on the subject is within the frame of the interview. (McCammon, 2016) One could say that structured interviews are best when quantitative and objective information is of interest while non-structured interviews work well while looking for a deeper understanding and subjective answers is not seen as an obstacle. (Ryen, 2004)

The interviews in this project will be performed in a semi-structured manner. Meaning that a vague skeleton and some important questions will be prepared beforehand, but the interviewee is allowed to broaden their answers and follow up questions will be asked as they appear to the interviewer. The semi-structured format is chosen since the subject of developing a new product is not an entirely quantifiable one, while some information is required to make the project a success. A certain set of questions that must be brought up will be prepared for the interviews. Since the product in question is going to affect several departments (e.g. E&E, software, assembly) the same questions will be addressed to several interviewees so that the differences in their answer can be compared. Also, input from one interviewee can be forwarded to others, that way, a sort of dialogue might occur between the departments on the subject. The interviews will be documented by taking notes.
2.1.3 Observations

Observations will be used as a complement to the interviews. Observations do not provide the insight that the answers from a knowledgeable person might result in. They might, however, be less subjective since one actually sees what happens, instead of hearing about it. (Bohgard, et.al. 2015) The interviewee could have a certain opinion as to what would be the best alternative to solve the problem at hand, which might shape the answers and suggestions given during interviews. Observations will hopefully help the author to create his own opinion on the matter, putting him in a more favourable position when evaluating the information gained from the interviews. Observations are aimed at getting a better understanding of the ART’s construction and how it’s made, which is why both the production line and the finished product is of great interest.

2.1.4 Study of similar products

A competitor analysis is a common method to learn what to do and what to avoid when designing one’s own product. To see how others have solved common problems is a valuable source of inspiration. Analysing data from competitors is a beginning, but it is recommended to do the measuring and to physically inspect the competing products oneself, if one can get access to them. (Ulrich and Eppinger, 2012) In this case competitive products will be observed, as will products within Volvo itself. Many products already exist on the ART that has properties similar to the product in focus, i.e. enclosed electronics mounted on the frame of the load unit.

2.1.5 Documents at VCE

Information is to be gathered from internal documents such as requirement specification, general information on the construction machines, gathered statistics, technical investigations and CAD-models. The documents will be referenced to if possible.

2.1.6 Setting up the requirement specification

Setting up a list of requirements is done for the purpose of defining a direction for the product development process, but also to serve as reference when evaluating the product during the process. (Liedholm, 1999) The requirements will be based on several sources such as technical requirements within VCE, opinions and experiences received from employees at VCE, requirements derived from the ICCS-module (the chosen intelligent node), and on the project directives for this thesis.
Some guidelines for the requirements inspired by Liedholm (1999) can be found in the list below:

- Since the requirements are set up as guidelines for the development process and long before any decisions have been taken on a final design they should be phrased so that they are independent of any solutions.
- When possible they should be measurable so that it can be clearly judged whether the requirement has been fulfilled or not.
- The difference between definite requirements and more loose goals or wishes should be distinct.

In the end of the project, the requirements will be evaluated, looking into if they were fulfilled, and if not, what is missing.

2.2 Phase 1: Concept generation

Ulrich and Eppinger (2012), among other authors, recommend starting out with a large group of concepts that will be filtered out as the process moves onwards. This is the part where all these concepts are to be generated. Techniques for how to generate part-concepts and put them together into concepts for the whole product will be described below.

2.2.1 Identifying separate functions

Since concept generation on a whole product would be too unorganised and too cognitively demanding to produce a composed result, some splitting up of the product is required. The splitting should result in parts that each fulfil a necessary function for the product to work and be able to fulfil the defined requirements. In other words: They are supposed to be discrete and defined by a single feature. This is – which might be suspected – not an easy task. In most products, functions tend to be more or less entwined with each other, or at least have the possibility to be (e.g. both opening and unlocking a door with the same handle are two functions in one feature commonly found in toilets for disabled).

When identifying these functions the analogy of a tree inspired by Liedholm (1999) will be kept in mind (Figure 2) since it gives perspective on where the project stands in the function analysis process.
What might be noticed in this particular development process is that the black box model and generation of the technical processes has been skipped since this thesis began with the specific goal to develop an encapsulation for the ICCS-module. That is, the technical process has been established to be an encapsulation of some sort. The goal of the analysis in this thesis is to find logical functions to divide the enclosure into.

2.2.2 Generating concept parts: Brainstorming

A popular technique to come up with a great amount of initial ideas to pick from. The technique is basically to go into a mind-set of coming up with all sorts of ideas during a brainstorming session. Even silly, impossible ideas are encouraged, evaluation or judgement is prohibited during the session, and everything that comes to mind should simply be recorded. The evaluation will have to wait until after the session. (Ullman, 2010)

2.2.3 Generating complete concepts: Morphological matrix

The morphological matrix is a valuable tool to come up with concepts in the beginning of a design process. It is well suited to be used when the product’s task and the functions needed to realise it are known, but the means to fulfil the functions are still to be decided. This helps the designer to produce solutions that can be sorted through later on. One way to do it is to line up each of the needed functions in the first column, and let rows originate from these in which possible means will be listed for each function. See Figure 3 for a practical example. Each of the means should be on about the same level of detail, and although it is good for the creativity to have a lot of possibilities to choose from, the matrix should be kept to a manageable size. (DD4U, 2016)
2.3 Phase 2: Concept evaluation and selection

In this phase the evaluation will be performed by developing and evaluating a set of concepts in parallel to get a better understanding of which that are showing potential when it comes to implementing them. This is to avoid throwing away good alternatives, which might happen when betting all resources on one concept early on as described in Ullman (2010).

2.3.1 Screening and scoring: Phug’s matrix

This technique is a popular screening tool when having several concepts to choose from. It might be hard for a designer to compare the concepts just by looking at them, but by using Pugh’s matrix (see Figure 4) the designer can get a broader view of the usefulness of each concept. Each concept receives a grade that hints at how well it complies with the selection criteria in the left-hand column. The grading of a concept is based on a reference concept whose grades are zero in all categories. The other concepts can either be rated as better (+), equal (0) or worse (-) than the reference when looking at how well their solutions live up to the task they are supposed to fulfil. (Ulrich and Eppinger, 2012)
After the screening a handful of concepts are picked out for further evaluation. Some might be modified right after the screening to remove flaws in an otherwise good concept. All these candidates are then compared in Pugh’s matrix again. However, this time it is slightly modified to take more details into consideration (see Figure 5).

- Points received in a selection criterion will now be multiplied with a weight specific to that criteria to make the criteria differ in importance.
- The concepts will be awarded points on a five-graded scale instead of a three graded one.

This weight is multiplied with each concept’s corresponding solution before the total score is calculated. An example of the scoring matrix can be found in Figure 5. (Ulrich and Eppinger, 2012)

In the last evaluation the opinions of engineers and assembly personnel at Volvo will be taken into consideration. Their opinions will work as a kind of combination of a designer team voting and testing on customers.
2.3.2 Simple prototypes

Building and studying simple physical prototypes is a common effective method to prove the concepts function or to expand the understanding of a concept. Analytical prototypes are also a common tool for this purpose. Both formats have their own advantages; Physical prototypes are good for getting a hands-on understanding and to discover unanticipated phenomena occurring from something (e.g. impractical size) that would not have been accounted for in an analytical model. Analytical prototypes are more flexible than physical ones. If a parameter - like the material or the thickness of an edge – needs to be changed, an analytical model is superior. (Ulrich and Eppinger, 2012) This project will use simple physical prototypes for the purpose of visualising them so that they may be more accurately evaluated. Parametric CAD-models – i.e. analytical prototypes - will be used to visualise the whole of the product and the varieties available.

2.4 Phase 3: Detail design

During the detail design the functions that have been chosen so far are to be described and specified. Concepts concerning smaller objects will be treated e.g. how the screw holes should integrate with the seals, how thick and in what material the enclosure should be, what parts that would be recommended, etc. Suggestions on how the node might fit into the assembly will also be presented. The whole final concept will then be modelled in Catia V5. Calculations concerning the design will also be made during this phase.
3 Theory

In this chapter important knowledge for this thesis will be introduced, knowledge of CAN-systems and intelligent nodes, VCE’s articulated haulers as well as methods of sealing an enclosure and of dampening vibrations.

3.1 Construction equipment

Volvo Construction Equipment manufactures several different kinds of heavy equipment machines in production plants all over the world. Their main development centre for two of their products – the ART and WLO - is situated in Eskilstuna, Sweden. (Volvo, 2016)

3.1.1 Identity numbers

An important piece of information is the system concerning the identity number that the ARTs and WLOs are given at VCE. A generic example can be seen below.

Volvo X##Z

The X in the id-number is a letter standing for what kind of vehicle it concerns, in this case A for an ART and L for a WLO. The #s stand for digits indicating how large the vehicle is. The Z is a letter between B and H that declares what generation the vehicle belongs to. Additional letters occur on some extra equipped machines. An example of an id-number belonging to an ART of generation F with a capacity of about 40 (short\(^1\)) tonnes is presented below. As can be seen the ART is extra equipped, “FS” stands for fully suspended which is a version of the ART where the whole suspension of the load unit is exchanged.

Volvo A40F FS

(Volvo, 2016)

3.1.2 ART

The articulated hauler is a machine made to transport heavy loads in harsh environments. It has to be able to drive on very uneven and muddy surfaces in almost any weather. At Volvo CE the development takes place in both Eskilstuna and Braås.

\(^{1}\) Short ton = 2000 pound = 907.18474 kg. Commonly used in USA and Canada.
Most of the assembly and manufacturing take place in Braås. The cab, including the main E&E and ECUs, is manufactured in Hallsberg and shipped to Braås.

The digits in the ART’s id-number can be one of the following: 25, 30, 35, 40, 45 and 60, indicating approximately how much weight the hauler can load in (short) tonnes. As of now H is the latest generation of haulers. (Volvo, 2016)

![Volvo A60H articulated hauler](Volvo, 2016)

### 3.1.3 Existing standard components in the ART’s load unit

Each of the E&E components in the ART’s load unit is going to be listed and commented below. The information has been collected during interviews with employees at Volvo. The component’s locations are indexed in Figure 7.

![Overview of the load unit on an A40 without bucket. E&E components have been pointed out.](Figure 7)
Enclosing and Mounting an Electronic Component on Articulated Haulers

**IMU, Inclination sensor (A)**

The sensor measures the unit’s angles in the horizontal plane. During an interview with an engineer in hardware at the E&E department, an idea emerged that it may be possible to connect the node to the already existing CAN-node (250KBAud) in the IMU. This would result in even fewer cables going between the load and the pull units which would be a cost- and work-reducing change. However, there is a thick bundle of cables passing between the load unit and the pull unit. The electrical cables are all routed through a plastic tube for protection, if the number of electrical cables were to be decreased, the plastic tube would be made thinner. This might increase the risk of the cables getting pinched. Keeping the plastic tube at the same thickness to prevent this from happening could instead result in that the electrical cables get too much space to move on and become torn by moving against each other and the walls of the pipe.

**Temperature sensor (B)**

On both axles. Monitors the temperature of the fluids cooling the brakes.

**Tachometer (C)**

On the front drive axle. Monitors the RPM of the wheels, which is important data for the Automatic Traction Control system (ATC).

Possible obstacle: It is not completely known if the ICCS-module could delay the signal too much for it to be responsible for the signals to the ATC, since it is very dependent on reaction time.

**Load sensors (D)**

Mounted just inside of the left front and right back wheels (see Figure 8 below). As pressure is placed on them, the resistance is varied in the current going through the sensor, which is utilised to calculate the load that is causing the pressure.

![Figure 8](image-url)

*Figure 8 – The left figure illustrates the load sensor up close. The figure to the right illustrates the sensors placement and their wiring highlighted in blue.*
**Back lights (E)**
Heightens the visibility of the ART from behind in dark environments.

**Turning signals (F)**
Possible obstacle: The turning signal has a diagnostic function that heightens the frequency of the indicator in the cabin if an error is noticed in any of the signals. This could be an obstacle when connecting the signals to CAN.

**Reversing camera (G)**
Assists the driver visually when reversing. Not to be included in the CAN-system.

**Angle sensor (H)**
Keeps track of the loading buckets angle when tipping so that the driver can see the incline of the bucket on a screen in the cabin. Situated practically at one of the bucket’s two pivot points.

**Back-up alarm (I)**
Sounds when the machine is reversing.

**License plate lamp (J)**
Lights up the license plate.

**Reversing lamp (K)**
Lights up for the reversing camera

**3.1.4 Options in the ART’s load unit**

It is common for the ART to carry extra equipment such as joint lubrication systems, alternate configurations of the tailgate or fire extinguishing systems. Albeit not being present on all machines, they all have their own reserved spot, which is why it would be ill advised to pick a place for the node without considering these components. Interviews and observations in the assembly as well as studies of internal documents resulted in Figure 9 and the list below.
**Enclosing and Mounting an Electronic Component on Articulated Haulers**

- Fire extinguisher (Ax)
- Box for lubrication system. (Bx)
- Magnetic vent for air lines (Cx)
- The central lubrication system has a distribution box in the back (Red)
- Lightweight underhung ARTs have what they call a “mountain top” while the heavier ones have two big hydraulic cylinders taking up a lot of space (Green)

### 3.1.5 Cables in the ART’s load unit

The cables are routed in a main harness branching of through manifolds out to the components. The main layout has been highlighted in the overview below (Figure 10). A point to note is the larger branch in the beginning of the second “square” coming from the front. This can be described as a “fork” where the main harness splits into two branches, both of them carrying cables that are to be connected to the node.
3.1.6 Mounting constraints

Some constraints on how and where the node can or should be mounted have been identified during the interviews with the engineers and assembly personnel. These constraints can be boiled down to the following:

- Holes cannot be drilled directly into the frame’s vertical walls. This is because of durability reasons. Anything that is to be mounted on the walls needs to be on some kind of ledge, shelf, bracket etc. that has been welded there. The horizontal surfaces are open to drilling however.
- Respect other components spaces. To be noted is that optional components have their own reserved space as well, even if they are not on a specific machine, that spot is of limits. I.e. the available space is much more limited than would seem when looking at a standard ART. See 3.1.3 and 3.1.4 for details.
- Consider how the assembly personnel would have to work. Avoid placements that are problematic because of an odd angle or tools not reaching because of components sitting tightly together.
- Holes in the frame or in brackets welded to the frame cannot be threaded since it would require the threads to be (painstakingly) covered when painting the frame. Meaning that bolts and nuts will be preferred over screws when mounting anything to these areas.

Figure 10 – The main cable harness in the pull unit highlighted in orange.
3.1.7 Need of design for service

On the articulated hauler and wheel loader E&E-components are often replaced, rather than serviced. This is because it would be more expensive (more hours of standstill for the machine) to send a technician to care for the machine in the field, instead of simply ordering a new component. Enabling easy service of the component is, in other words, not a recommended spending of resources. However, what could be useful is the facilitation of replacing only the faulty part of the component, i.e. using an enclosure which can be opened, opposed to the completely moulded models often used on the machines today. This could lessen the number of work hours and material costs invested in service. Of course- considering that increases in development and production costs probably will follow - this effort has to be motivated, i.e. it should be reasonable to assume that the component will be replaced so many times that enough expenses are saved. The assumption that production costs will rise from creating a node that can be opened is not completely verified however. Therefore it seems motivated to inquire how much these replacements will affect the costs of the node and come to a decision on whether it is worth designing for service or not.

From the circumstances it is difficult to make an estimation of the total costs, what can be done is to look at how much VCE has to put out through warranty for other components. Of course, it can be argued that reduced costs for the customers would be indirectly beneficial to VCE, but this will have to be a “hidden” benefit in this case. A component that would seem sufficiently similar to the node (in terms of technical level and placement) is the back-up alarm (I) located on the top of the load unit’s frame (see 3.1.3 above). It is also located on the WLO. Data on this component from both the ART and the WLO has been used to calculate an estimation of the costs of having an open able vs. a completely moulded enclosure. To protect confidential information, the calculations cannot be published. The result of the calculations was inconclusive; they are in slight in favour of the open able alternative. However, considering the uncertainties surrounding the numbers it cannot be concluded that the open able alternative is either better or worse than the completely moulded one in terms of costs. The result of this conclusion will be that open able enclosures will be further looked into, whether the final product will be of this kind or not is to be decided at a later stage of the development process.

3.2 CAN-bus

A prior investigation at VCE resulted in the recommendation of an intelligent node – also referred to as an ICCS-module (Intelligent Command and Control Systems, see Figure 11) - from Würth Elektronik that could be used a sort of control unit for several components not equipped with CAN. The ICCS-module was used in a previous master’s thesis written at VCE (Krainer, 2016). The same node is being used in this thesis. Specific data for the ICCS-module can be found in Appendix 1 – ICCS-module’s datasheet.
**Theory**

**Figure 11 – ICCS 64 CAN-node (Würth Elektronik, 2013)**

CAN - standing for Controller Area Network - is a system to make digital communication between intelligent nodes easier and more robust. It was invented in the mid 1980’s by Robert Bosch GmbH (Pazul, 2002).

**Figure 12 – Schematic illustration of a CAN-bus with 120 Ohm resistances between CAN-H and CAN-L serving a signal termination.**

The components in a CAN-bus are called nodes (see Figure 12). The nodes can be sensors, actuators, ECUs, etc. The nodes are ordinary components in a network, what makes the network into a CAN-bus is the fact that they utilise the CAN-protocol. The risk of disturbances affecting the messages in a CAN-system is very low thanks to the message depending on two separate signals being required (CAN-high and CAN-low) instead of one. A pair of resistors is to be found at the ends of the CAN-H and CAN-L lines, these serve as signal termination, making sure that the signal is not reflected back to the nodes it has already passed. Except from the CAN-high and –low signals which require one cable each, the CAN-node demands a power inlet cable and a ground cable, meaning that at most four cables will be needed in the harness. (Pazul, 2002)
The CAN-protocol is message based, this means that there is no need for an organising computer that sees to that the messages reaches the right node, neither does the messages need to be addressed to a special node since all messages goes to all nodes. An advantage with a message based protocol is that a new node can be added without much complication since it will receive all messages without having to be introduced to the other nodes. (Pazul, 2002)

### 3.3 Generally on sealing

The node is to be sealed from intrusion of unwanted liquids, particles and gases. To achieve this, the shell itself needs to contain no holes though which any of these can pass, that is, ventilation of any kind needs to be secured in some way. Joints between the box’s parts, the box and its lid, etc. and all kinds of ports needs to be tight enough to fulfil the established requirements.

The sealing will be tried against the International Electro technical Commission’s (IEC) measurement system International Protection (IP). The IP value is displayed in the format below.

\[
\text{IPXY}
\]

Where **X** signifies the device’s protection against ingress of foreign objects and access of individuals, while the **Y** signifies how resistant it is against ingress of liquids. As can be seen, the first number describes protection against two similar, but different phenomena. They usually have the same degree. The protection against access of individuals is meant to be for the protection of individuals, not the component, i.e. the point is that an individual should not be able to reach anything hazardous inside the enclosure. The **X** and **Y** are usually digits, however, if protection against high pressure is needed a ‘K’ might be added to the liquid number (see Table 1). The protection in the respective group is usually better the higher the degree. The exception is that the liquid rating only includes all lower digits up until IPX6K, i.e. IPX7 would not include protection against anything else than what is specified for that particular degree. (SIS, 2013) Table 1 provided below describes what each degree implies for the first number and Table 2 does the same for the second one.
### Table 1 – Interpretation of the first number (SIS, 2013)

<table>
<thead>
<tr>
<th>Degree</th>
<th>Protection against ingress of foreign objects</th>
<th>Protection against access (test probe may penetrate, but maintains sufficient distance from hazardous parts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Not protected</td>
<td>Not protected</td>
</tr>
<tr>
<td>1</td>
<td>Objects equal to or greater than 50mm</td>
<td>Back of hand (test probe with diameter of 50mm)</td>
</tr>
<tr>
<td>2</td>
<td>Objects equal to or greater than 12.5mm</td>
<td>Finger (test probe with diameter of 12mm)</td>
</tr>
<tr>
<td>3</td>
<td>Objects equal to or greater than 2.5mm</td>
<td>Tool (test probe with diameter of 2.5mm, and length of 100mm)</td>
</tr>
<tr>
<td>4</td>
<td>Objects equal to or greater than 1mm</td>
<td>Wire (test probe with diameter of 1mm, and length of 100mm)</td>
</tr>
<tr>
<td>5</td>
<td>Dust protected (no effect on function)</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Dust tight (no dust)</td>
<td></td>
</tr>
</tbody>
</table>

### Table 2 – Interpretation of the second number (SIS, 2013)

<table>
<thead>
<tr>
<th>Degree</th>
<th>Protection against ingress of liquids</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Not protected</td>
</tr>
<tr>
<td>1</td>
<td>Water dripping vertically</td>
</tr>
<tr>
<td>2</td>
<td>Water dripping, enclosure tilted up to 15°</td>
</tr>
<tr>
<td>3</td>
<td>Spraying water, up to 60° angle from vertical</td>
</tr>
<tr>
<td>4</td>
<td>Splashing water, any direction</td>
</tr>
<tr>
<td>4K</td>
<td>Splashing water, any direction (increased pressure)</td>
</tr>
<tr>
<td>5</td>
<td>Jetting water, any direction</td>
</tr>
<tr>
<td>5K</td>
<td>Jetting water, any direction (increased pressure)</td>
</tr>
<tr>
<td>6</td>
<td>Powerful jetting water, any direction</td>
</tr>
<tr>
<td>6K</td>
<td>Powerful jetting water, any direction (increased pressure)</td>
</tr>
<tr>
<td>7</td>
<td>Temporary immersion in water</td>
</tr>
<tr>
<td>8</td>
<td>Continuous immersion in water (at least as long as for 7)</td>
</tr>
<tr>
<td>9K</td>
<td>Water during high-pressure / steam-jet cleaning, any direction</td>
</tr>
</tbody>
</table>

Although the second number concerns all liquids, water is usually the one tried for since it a relatively challenging liquid to keep out. It is advisable to keep this in mind since
the effectiveness with which the seal is penetrated could vary depending on the liquid. (Rogers, 2016)

### 3.4 Heat dissipation from sealed enclosures

Both electronics (Slotnick, 2016) and seals (Castleman, et.al. 2014) take damage from high and low temperatures and sudden variation within sealed enclosures. The lifetime of many electronic components - like capacitors - are greatly influenced by heat. A rise in temperature with 10 °C could shorten the lifetime with as much as 50 %, e.g. 32 years lifetime at 45 °C is reduced to 16 years at 55 °C. (Slotnick, 2016) The datasheet for the node (Appendix 1 – ICCS-module’s datasheet) lists the nodes operating temperature as spanning between -40 °C and 85 °C (standard industrial specifications). Inside a completely sealed enclosure the heated air would have nowhere to go, which makes for a very inefficient cooling. Under the worst conditions (warm climate, long run-time, etc.) it does not seem unlikely for it to reach above recommended temperatures. To know how to optimise the design for cooling a simple estimation should be made while assuming these conditions.

A method for approximating the ambient temperature inside the enclosure ($T_i$) will be presented below. The calculations and assumptions are taken from heatsink calculator (2016). To approximate $T_i$ some assumptions will have to be made concerning the layout inside the enclosures:

- The heat is dissipated evenly across the ICCS-module (ignores that processors and capacitors will produce more heat than other components).
- The inside of the enclosure is uniform and does not contain any structures which might obstruct the air flow.
- The heat inside the enclosure is dissipated through natural convection and radiation (can easily be modified to conduction if the enclosure should be filled with potting compound).
- Laminar (“smooth”) flow within enclosure.

These assumptions might be more or less true depending on the final concept. They will, however, provide a hint about whether the cooling is sufficient or if it needs further modifications.

![Figure 13](image)

*Figure 13 – How the enclosure and its heat dissipation is viewed when taking the above assumptions into consideration. (heatsink calculator, 2016)*
The areas of vertical walls will be added up and counted as one wall, but the bottom and top walls will have to be calculated on their own. The calculations used are declared below:

**Variables:**

\[ A_{\text{inend}} = L_i \times W_i \] Internal area of top/bottom \([m^2]\)

\[ A_{\text{inv}} = 2H_i \times (L_i \times W_i) \] Internal area of vertical walls \([m^2]\)

\[ A_{\text{intot}} = 2A_{\text{inend}} + A_{\text{inv}} \] Internal area of all walls \([m^2]\)

\[ A_{\text{exend}} = L_e \times W_e \] External area of top/bottom \([m^2]\)

\[ A_{\text{exvert}} = 2H_e \times (L_e \times W_e) \] External area of vertical walls \([m^2]\)

\[ A_{\text{extot}} = 2A_{\text{exend}} + A_{\text{exvert}} \] External area of all walls \([m^2]\)

\[ A_{\text{tot}} = (A_{\text{intot}} + A_{\text{extot}}) / 2 \] Approximate total area of walls \([m^2]\)

\[ h_{\text{imb}} \] Convective heat transfer coeff. to internal bottom \([W / m^2 \cdot K]\)

\[ h_{\text{int}} \] Convective heat transfer coeff. to internal top \([W / m^2 \cdot K]\)

\[ h_{\text{inv}} \] Convective heat transfer coeff. to vertical surfaces \([W / m^2 \cdot K]\)

\[ h_{\text{imrad}} \] Radiative heat transfer coeff. to internal surfaces \([W / m^2 \cdot K]\)

\[ h_{\text{exrad}} \] Radiative heat transfer coeff. from external surfaces \([W / m^2 \cdot K]\)

\[ k \] Thermal conductivity of the walls \([W / m \cdot K]\)

\[ Q \] Total heat generated by the module \([W]\)

\[ R_{\text{imb}} \] Convection thermal resistance (TR) to internal bottom \([K / W]\)

\[ R_{\text{int}} \] Convection TR to internal top \([K / W]\)

\[ R_{\text{inv}} \] Convection TR to internal vertical surfaces \([K / W]\)

\[ R_{\text{exb}} \] Convection TR from external bottom \([K / W]\)

\[ R_{\text{ext}} \] Convection TR from external top \([K / W]\)

\[ R_{\text{exv}} \] Convection TR from external vertical surfaces \([K / W]\)

\[ R_{\text{imrad}} \] Radiation TR between module and external walls \([K / W]\)

\[ R_{\text{exrad}} \] Radiation TR from external walls \([K / W]\)

\[ R_{\text{cond}} \] Conduction TR thermal resistance of walls \([K / W]\)

\[ R_{\text{intot}} \] Total thermal resistance for all internal walls \([K / W]\)

\[ R_{\text{extot}} \] Total thermal resistance for all external walls \([K / W]\)

\[ T_i \] Average ambient air temp. inside the enclosure \([K]\)

\[ T_{is} \] Average surface temp. of inner enclosure walls \([K]\)

\[ T_{es} \] Average surface temp. of external enclosure walls \([K]\)

\[ T_e \] Average ambient temp. of external air \([K]\)
Enclosing and Mounting an Electronic Component on Articulated Haulers

$t$ Thickness of walls $[m]$

$\varepsilon$ Surface emissivity of enclosure $[W/m^2]$ 

$\sigma = 5.67 \times 10^{-8}$ Stefan-Boltzmann constant $[W/m^2K^4]$

$L'_{in} = \frac{L_{in}W_{in}}{2(L_{in}+W_{in})}$ $[m]$

$L'_{ex} = \frac{L_{ex}W_{ex}}{2(L_{ex}+W_{ex})}$ $[m]$

Convection thermal resistance between ICCS-module and bottom:

$$R_{inb} = \frac{1}{h_{inb} * A_{inend}} \quad (1)$$

Where

$$h_{inb} = 0.59 * \left( \frac{T_i - T_{is}}{L'_{in}} \right)^{\frac{1}{4}} \quad (2)$$

Convection thermal resistance between ICCS-module and top:

$$R_{int} = \frac{1}{h_{int} * A_{inend}} \quad (3)$$

Where

$$h_{int} = 1.32 * \left( \frac{T_i - T_{is}}{L'_{in}} \right)^{\frac{1}{4}} \quad (4)$$

Convection thermal resistance between ICCS-module and vertical surfaces:

$$R_{inv} = \frac{1}{h_{inv} * A_{inv}} \quad (5)$$

Where

$$h_{inv} = 1.42 * \left( \frac{T_i - T_{is}}{H_i} \right)^{\frac{1}{4}} \quad (6)$$

Radiation thermal resistance between ICCS-module and internal surfaces:

$$R_{inrad} = \frac{1}{h_{inrad} A_{intot}} \quad (7)$$

Where

$$h_{inrad} = \frac{\sigma (T_i + T_{is}) (T_i^2 + T_{is}^2)}{\frac{1}{\varepsilon} + \frac{1}{1 - \varepsilon}} \quad (8)$$
Conduction thermal resistance between internal and external walls

\[ R_{\text{cond}} = \frac{t}{kA_{\text{tot}}} \quad (9) \]

Convection thermal resistance between external surface and ambient air

Equation (1) to (6) can be used for these calculations as well. The difference is that all and measurements must be replaced by the exterior counterparts. This goes for the temperatures as well. That is

\[ T_i - T_{is} \] is to be replaced by \( T_{es} - T_e \)
\[ T_i + T_{is} \] by \( T_{es} + T_e \)
\[ T_i^2 + T_{is}^2 \] by \( T_{es}^2 + T_e^2 \)

Radiation thermal resistance between external surface and ambient air

\[ R_{\text{exrad}} = \frac{1}{h_{\text{exrad}}A_{\text{extot}}} \quad (10) \]

Where

\[ h_{\text{exrad}} = \varepsilon\sigma(T_{es} + T_e)(T_{es}^2 + T_e^2) \quad (11) \]

Finding \( T_{es} \)

A value for \( T_{es} \) is to be found by satisfying the equation below, this can be done by hand but an easier way would be to use the “Goal seek”-function in Microsoft Excel.

\[ R_{\text{extot}}Q - (T_{es} - T_e) = 0 \quad (12) \]

Where

\[ R_{\text{extot}} = \left(\frac{1}{R_{\text{exrad}}} + \frac{1}{R_{\text{exb}}} + \frac{1}{R_{\text{ext}}} + \frac{1}{R_{\text{exv}}}\right)^{-1} \quad (13) \]

Finding \( T_{is} \)

\[ T_{is} = R_{\text{cond}}Q + T_{es} \quad (14) \]
Finding $T_i$

$T_i$ is found with the same method as $T_{es}$ above, i.e. through finding a value that satisfies

$$R_{intot}Q - (T_i - T_{is}) = 0 \quad (15)$$

Where

$$R_{intot} = \left(\frac{1}{R_{inrad}} + \frac{1}{R_{inb}} + \frac{1}{R_{int}} + \frac{1}{R_{inv}}\right)^{-1} \quad (16)$$

Finding $Q$

Sipex (2006) gives that the generated heat $Q$ can be calculated as the power difference between what enters and what comes out of a component. This is done by multiplying the current going through the node with the voltage difference:

$$Q = \Delta P = I \ast (V_{in} - V_{out})$$

3.4.1 Heat sinks

Heat sinks are a very common method used to cool equipment passively. They are often mounted on the exterior of an enclosure and simply work by expanding the available area from which heat can dissipate through convection to the ambient air. Therefore they are shaped to have a large area-to-volume ratio. Lee (1995) A common model is the planar heat sink seen in Figure 14.

![Planar heat sink](image)
3.5 Isolators

Isolators are widely used to protect equipment against vibrations and shocks. In this section the basics on choosing and installing isolators will be explained.

3.5.1 Centre of gravity and elastic centre

Elastic centre is the point where the stiffness of the system can be reduced to one value, i.e. where the isolators “mean” damping axes meet (see Figure 15). The mounted equipment will rotate around the elastic center and the shear forces felt by the isolators will depend on the distance (e) to the center of gravity. (Lord, 2016)

![Figure 15 – Elastic and gravitational centres in a suspended component (Lord, 2016)](image)

Centre of gravity installation is when the elastic centre and centre of gravity are in the same spot. It is often advantageous to install damping in this fashion since the isolators will not be subjected to shear forces in the same extent. In Figure 16 an illustration of the effect of shear forces on a system where the centres are not in the same spot. This is not necessarily an unwanted effect; it depends entirely on the design and intended application of the system in question (Lord, 2016)

![Figure 16 – Illustration of how a response might look from shear forces (Lord, 2016)](image)
Depending on where the isolators are fastened the system can have up to six degrees of freedom (df), as it can vibrate vertically in one direction, horizontally in two and rotate in three. The number of df is largely dependent on the elastic centre’s position in respect to the centre of gravity. If they are completely aligned all rotational movement is restricted. Rotational movements are hard to remove completely, however, and will often produce a second natural frequency in the horizontal planes referred to as $f_{n,M2}$ below. The system in Figure 15 and Figure 16 will experience moments in all degrees, but much more so around the “longitudinal” axis. (DB engineering, 2016)

3.5.2 Temperature’s effect on damping

The ambient temperature often has great impact on the isolator’s damping properties. The natural frequency of a material is heightened at low temperatures and lowered at high temperatures; consequentially the transmissibility does the same. (Lord, 2016) This makes it difficult to account for all circumstances when dealing with an object working in a broad temperature-range, such as the ART. Choosing an isolator material which is relatively consistent throughout temperature variations is, in other words, important to the system’s performance. In

Figure 17 below, several damping material’s response to varying temperatures are compared to each other. To be noted is the difference in the stiffening factor’s response to temperature variations.

Figure 17 – The stiffening factor’s response to temperature variations within different damping materials. (Lord, 2016)
3.5.3 Calculations

Some important characteristics to know when doing calculations on an isolated system:

- $f_n$: Vertical natural frequency [Hz]
- $f_d$: Forced vertical natural frequency [Hz]
- $f_{n,M1}$: Translational natural frequency in horizontal axis [Hz]
- $f_{n,M2}$: Momentual natural frequency in horizontal axis [Hz]
- $T$: Transmissibility
- $G_T$: Shock transmission
- $\Delta_D$: Dynamic linear deflection following a shock [m]
- $K_V$: Vertical spring coefficient $\frac{N}{mm}$
- $K_H$: Horizontal spring coefficient $\frac{N}{mm}$
- $V$: Velocity of the equipment during shock $\frac{m}{s}$

Not to be forgotten is to consider how the suspension configuration affects the movements of the system covered above since this decides if there will be horizontal natural frequencies to calculate. Beginning with the vertical axis; $f_n$ of isolators are usually provided in the datasheets, however the static load on the isolator from the component changes the natural frequency. Lord (2016) provides the following formula when the dynamic load is outside of the rated load:

$$f_n = f_{nn} \times \sqrt{\frac{P_R}{P_A}}$$

Where

- $f_{nn}$: The nominal (original) natural frequency [Hz]
- $P_R$: Rated (original) load [Kg]
- $P_A$: Actual load [Kg]

$f_d$ has to be approximated or measured since it is the frequency exerted onto the equipment by the supporting structure (the ART). Having these two, the “isolation region” can be found. The isolation region is where the transmissibility $T \leq 1$ (DB engineering, 2016).
Enclosing and Mounting an Electronic Component on Articulated Haulers

The transmissibility is a measurement of the isolation; it is the ratio of the dynamic output to the dynamic input. When the transmissibility is above 1 the vibrations are being amplified, and it is the highest at the natural frequency. The isolation region starts when

$$\frac{f_d}{f_n} \geq \sqrt{2}$$

This can be used to get a value for where one wants the forced vibrations to be. (DB engineering, 2016) If the forced vibrations are larger than $$f_n \times \sqrt{2}$$ then the system will always be isolated. If not it will go through a rough patch of amplifications somewhere (see Figure 18).

With the help of the spring constants and the equipment’s dimensions the horizontal natural frequencies can be approximated by inserting the values from the equations below into Figure 19. (DB engineering, 2016)

$$\frac{H}{W} \text{ and } R = \frac{k_H}{k_v}$$

By doing so one receives the ratios

$$\frac{f_{n,M1}}{f_n} \text{ and } \frac{f_{n,M2}}{f_n}$$
From which the horizontal frequencies can be calculated. If the elastic centre and centre of gravity are aligned the ratio $\frac{H}{W}$ can be set to zero, meaning that $f_{n,M2}$ will be zero as well. (DB engineering, 2016)

When damping for shocks the important factor is the material’s ability to absorb a sudden burst of energy which is then released slowly to the equipment, i.e. the equipment gets the hit much slower than it would without the isolator. Three parameters that are usually studied when testing for shocks are the peak acceleration in Gs of the equipment, the duration of the shock (in milliseconds) and the shape of the shock pulse. There are several kinds of pulses such as triangular, rectangular and sinusoidal. The shock can be appreciated mathematically by looking at the instantaneous velocity change which can be calculated if one knows the three mentioned parameters. From this it is possible to calculate the shock transmission and the deflection:

$$G_T = \frac{V \times 2\pi f_n}{g} \quad \text{and} \quad \Delta_D = \frac{V}{2\pi f_n}$$

(DB engineering, 2016)
3.6 Gaskets

Gaskets of different materials and shapes have been applied in numerous ways for a long time to seal the joints of enclosures. To seal sufficiently in a certain medium under a certain pressure the gasket has to be exposed to the right amount of compression. What the right amount is depends on the gasket material. An example can be seen in Figure 20 below where leakage has been measured for five varieties of gaskets made from the material Poron Urethane. Each test was performed under the same water pressure (10.3 kPa) with the same dimensions on all gaskets. Each gasket was tested for five different compression rates. As can be seen from the graph, the higher the pressure, the better the sealing capacity. Consequently, softer materials have an advantage in that they require a small force to seal properly. (Rogers, 2016) This is confirmed by Ho (2009) who argues that soft seals better follow the profiles of surfaces than a harder material under the same stress. Also they are more forgiving when it comes to tolerances and relative component movements.

![Graph showing leakage results for five varieties of gaskets](image)

*Figure 20 – Graph displaying results from testing varieties of a gasket material (Rogers, 2016)*

However, one has to keep in mind that materials loses their tension after being compressed or pulled out for a while, to a greater or lesser degree.

Other important aspects to consider when choosing a gasket are its design and method of fastening. Some examples of gasket designs are stripping, die-cut, form-in-place and bulb extrusion, each with their own respective strengths and weaknesses.

**Stripping**

The gaskets are stripes cut from rolls of material. It is relatively cheap, but problematic when it comes to making the corners tight. In Figure 21 below a sample of three common corner joints is displayed. Of the three, the Dove Tail is the one deemed to be the tightest. (Rogers, 2016)
Die-cut

When the needed shape is complicated, or when the corners of a strip-gasket do not add up, this method might be more useful (see Figure 22). The gaskets are cut out with a steel-rule, water-jet, laser or other cutting tool. The material can be folded and cut to avoid creating scrap material. (Rogers, 2016)

Form-in-place

This method works well for very complicated gaskets which would be hard to produce any other way. The available materials are limited since it needs to be in liquid form when being applied directly to the device that it is going to seal (see Figure 23). It is then curated at room temperature. (Rogers, 2016)
Bulb extrusion

The materials available to this method can be very durable, making it a good choice if the seal need to withstand tough environmental conditions. Since they are hollow (Figure 24) they require a relatively small compression force to seal effectively. (Rogers, 2016)

![Figure 24 – Samples of bulb extruded gaskets (Rogers, 2016)](image)

3.6.1 Temperature’s effect on gaskets

Seals, no matter the material, are affected by temperatures. In the short term in that they expand or contract, thereby compromising the tightness of the enclosure, but also in the long term since their properties changes after being exposed to high temperatures for too long (Castleman, 2014). Higher than room temperature also serves as a stress inducer in seals since they will be put under increased pressure by the housing parts they are compressed between due to thermal expansion. This is according to Ho (2003) who asserts that “It is quite possible that an elastomer seal deformed in a standard housing can experience a tensile stress of 2–3 MPa due to installation and thermal expansion.” (p.2) meaning that the material chosen has to be quite tolerant, depending on the installation circumstances. Temperatures also affect the damping equipment, which can be seen in 3.5.2.

3.6.2 Gaskets in cable ports

The cable ports are definitely a hard spot to protect from ingression, but they need to be as safe as any other part of the node. The alternatives that exist here – apart from making the node completely cable-less – is either to install ports at the surface of the shell and use an IP-rated cable connector, or to run the cables themselves through the shell and protect the hole where the cables enter from ingression. Examples on existing solutions for similar situations can be seen in Figure 25. No matter what method that is chosen, this part needs to be as sturdy as the rest of the shell. This can be conceived by using heavy duty parts (like the cable connectors in Figure 25), or by covering the parts in some way so that they cannot be crushed against exterior objects.
Pressure can have detrimental effects on the seals in an enclosure if it is allowed to put strain on them during long periods of time. Over- and under pressure can arise both because of temperature differences and from changes in altitude. Making sure that the enclosure has sufficient venting capacity is important to the well-being of the ICCS-module. (Gore, 2016)

Another problem with sealed enclosures is the condensation that occurs when pressure rises relative to the pressure it was sealed in if the vapour has no way to escape. This means that components might get wet despite being perfectly sealed from outside moisture (Gore, 2016)

Figure 25 – Upper left: Cable connector (Phoenix Contact, 2016)  
Upper right: Cable passage (Rotex, 2016)  
Lower: Cable passage (Blue Sea, 2016)

Figure 26 – Examples of pressure equalizing valves (Gore, 2016; aGm, 2016)
A way to both even out the pressure inside and let vapour out of sealed enclosures without allowing water to get in is to use a vent that does just that. On the market there are several producers and variants of vents, everything from adhesive patches to threaded ones that screws/bolts into the enclosure, some examples are displayed in Figure 26. (Gore, 2016; aGm, 2016) A problem with these might be that vapour is also allowed to get inside the enclosure when the surrounding humidity rises, meaning that the components inside the enclosure needs to be more tolerant against humidity.

### 3.8 Potting compounds

Potting compounds is a one- or two component fluid that is cured after it has been poured over the electronics inside the enclosure. It can present an excellent protection against fluids as well as vibrations and shocks, although it renders the component more or less irreparable. (Thomas, 2016) Some potting compounds can also make the dissipation of heat more effective since it has a much higher thermal conductivity than air. (Epoxies, 2016) However, special compounds with high thermal conductivity are quite expensive compared to usual potting materials. (Hallstrom, 2016) No matter what kind of compound is chosen the initial costs will be high since moulds and dispensing machines will have to be purchased (Epoxies, 2016).

![Figure 27 – Example of how a potting compound might look (Ryatech, 2016)](image)

### 3.9 Enclosure manufacturing techniques and materials

A discussion with a lecturer at Linköping University led to the conclusion that casting will probably be the best method for manufacturing the enclosure, mainly because of the high IP-requirement. What kind of casting that should be used, will have to be decided during the detail design phase.

Although the material will not be getting the most attention of the design parameters during this thesis, it should be looked into to get a grip on the measurements of the enclosure and to be able to approximate weight, thermal properties, etc. Aluminium based alloys have a high strength to weight ratio, which is one reason as to why they are commonly used in these applications. For each of the casting techniques looked into below, a possible aluminium alloy will be studied as well.
From an environmental perspective, aluminium is a very energy consuming and harmful metal to produce. On the other hand, since the properties stay the same independently of the number of times the metal is melted down and reused it is convenient in terms of recycling. Recycling aluminium only requires about 5% of the energy that it would take to produce the same amount from scratch. (The aluminium association, 2011)

3.9.1 Die casting

Die casting is a very fast and precise method, commonly used in the automotive industry. It is good for creating complex 3-dimensional parts. Since there is no joints that can be compromised in a die cast part, it is an ideal method when high IP-rating is a priority. While the unit cost is low, the die itself is very expensive, meaning that it only pays off either after a very long time or in high volume-production. If the molten metal is forced into the die with high pressure it becomes possible to cast very complicated and/or thin geometries, the surface finish is also superior at high pressure. This technique renders little to no waste in terms of material, but it requires a great amount of energy to melt the alloys and keep them in that state during casting. One has to consider that the part is going to be ejected from the die, meaning that there cannot be any edges or other geometries that would make this impossible (see Figure 28 for an illustrative example).

The die casting aluminium alloy 384.0-F as it is called according to ANIS (American National Standard), is seen as a suitable enclosure material, mostly because it is used by other manufacturers in similar applications (which these are cannot be disclosed since it is confidential). The alloy consists of 77.3-86.5% Al, 10.5-12% Si, 3.0-4.5% Cu, and ≤ 3.0 Zn. Other notable substances existing in amounts ≤ 1.3% includes Fe, Mg, Me and Sn. Some important properties of this alloy are listed in Table 3 below. (MatWeb, 2016) A property that could not be found specifically for this material was the emissivity coefficient, the coefficient of anodised aluminium is used instead (Çengel & Turner, 2005).

Figure 28 – Impossible geometry for die casting since part cannot be ejected.
### Table 3 – Properties of the Die-Casting Alloy 384.0-F (MatWeb, 2016a; Çengel & Turner, 2005)

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultimate tensile strength (MPa)</td>
<td>331</td>
</tr>
<tr>
<td>Yield strength (MPa)</td>
<td>165</td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>2.823</td>
</tr>
<tr>
<td>Coefficient of thermal conductivity (W/m °K)</td>
<td>92</td>
</tr>
<tr>
<td>Coefficient of thermal expansion (µm/m °K)</td>
<td>20.8 (linear)</td>
</tr>
<tr>
<td>Surface emissivity (data could not found, using anodised Al instead) (no dimension)</td>
<td>0.82</td>
</tr>
</tbody>
</table>

#### 3.9.2 Sand casting

This method is very similar to die casting, but there are some important differences. One is that pressure is not used when the metal is inserted into the die cavity; it has to be poured with the help of gravity. This means that the created part will be more porous than if made with die casting. The lack of pressure and the tool’s surface leads to a rougher finish than what is achieved through die casting. The surface usually has to be treated afterwards by abrasive blasting, polishing, etc. Other differences include that each mould is only used one time since and is broken to eject the part. However, luckily, the tool cost is very low, making this an affordable method when producing low to medium volumes. The cycle time is typically around 30 minutes. Both the cycle time and the surface finish are affected by how the sand is bonded together. Usually the sand is mixed with either clay or synthetic materials. Synthetic bonding is usually the better choice both in respect to surface and time. (Thompson, 2007)

The fact that the tool is disposable also works in favour of some geometry which cannot be made in die casts because of the problem described in Figure 28 above. The wall thickness is somewhat limited in sand casting; it should be within 2.5-130mm and is best kept constant throughout the part. The environmental impacts are similar to the ones from die casting. (Thompson, 2007)

Aluminium 356.0-T6 Sand cast is an alloy that is regarded as a good alloy for casting when both lightweight and strength is needed. It is typically used to manufacture casings with high strength requirements and other demanding applications, which seems suitable in this case. It is also relatively easy to weld for an aluminium alloy and has good machining characteristics. (Leitelt Brothers, 2016) The alloy consists of 90.1-93.3% Al and 6.5-7.5% Si. Other components are ≤ 0.60% and include Cu, Fe, Mg, Mn, Ti and Zn. The most relevant properties to this application are displayed in Table 4. As with the die casting alloy, the emissivity coefficient were taken from painted aluminium.
Table 4 – Properties of the sand casting alloy Aluminium 356.0-T6 (MatWeb, 2016b; Çengel & Turner, 2005)

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultimate tensile strength (MPa)</td>
<td>≥ 207</td>
</tr>
<tr>
<td>Yield strength (MPa)</td>
<td>≥ 138</td>
</tr>
<tr>
<td>Density (g/cm$^3$)</td>
<td>2.68</td>
</tr>
<tr>
<td>Coefficient of thermal conductivity (W/m K)</td>
<td>151</td>
</tr>
<tr>
<td>Coefficient of thermal expansion (µm/m K)</td>
<td>21.4 (linear)</td>
</tr>
<tr>
<td>Surface emissivity (data could not found, using anodised Al instead) (no dimension)</td>
<td>0.82</td>
</tr>
</tbody>
</table>
4 Requirements

This chapter will identify the requirements that the product shall be aiming to fulfil. These requirements are specific for this project, and should not be confused with VCE’s technical requirements, which are made in both more detail and broadness.

Table 5 – Specifications for the installation of the node

<table>
<thead>
<tr>
<th>Nr.</th>
<th>Description</th>
<th>Specification</th>
<th>Requirement /wish</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Protective enclosure</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Needs to be dust- and waterproof.</td>
<td>IP66K and IP69K</td>
<td>Requirement</td>
</tr>
<tr>
<td>2</td>
<td>Should be able to protect the node from <strong>vibrations</strong> that the ART is expected to produce.</td>
<td>Chosen damping is specified to tolerate the VCE test-procedures for vibrations.</td>
<td>Requirement</td>
</tr>
<tr>
<td>3</td>
<td>Should be able to protect the node from <strong>shocks</strong> that the ART is expected to produce.</td>
<td>Chosen damping is specified to tolerate the VCE test-procedures for shocks.</td>
<td>Requirement</td>
</tr>
<tr>
<td>4</td>
<td>Tolerates expected humidity in all working conditions and geographical areas.</td>
<td>The enclosure is expected to leave the module functioning after being exposed to a humidity level of 10-100%</td>
<td>Requirement</td>
</tr>
<tr>
<td>5</td>
<td>Should protect the node from mechanical damage coming from outside the shell. The node should not be damaged by forces from the enclosure budging, it should still be fully functional and the ingress protection is not to be compromised.</td>
<td>Tolerates Point load ≥ X kN Surface load ≥ X kN/cm² Shear load ≥ X kN Projectile hit of 0.5kg object falling from 5m height</td>
<td>Requirement</td>
</tr>
<tr>
<td>6</td>
<td>Cooling should be sufficient to keep the node within operating temperatures.</td>
<td>Average temperature inside enclosure should stay between -40 °C and 85 °C. Testing will only be done for the maximum temperature.</td>
<td>Requirement</td>
</tr>
</tbody>
</table>
The nodes ingress protection should not be compromised by pressure build or drop from temperature or altitude variations. The enclosure has the capacity of evening out expected pressure build or drop.

<table>
<thead>
<tr>
<th>Requirement 7</th>
<th>Place of node</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>Places where standard components and attachments are usually mounted should be avoided.</td>
</tr>
<tr>
<td>9</td>
<td>Screw holes cannot be placed in frame walls.</td>
</tr>
<tr>
<td>10</td>
<td>Custom tools should not be needed when mounting the node.</td>
</tr>
<tr>
<td>11</td>
<td>The node should be mounted and demounted with as few tools as possible</td>
</tr>
<tr>
<td>12</td>
<td>The cable length between each load sensor and the intelligent node should be minimised.</td>
</tr>
<tr>
<td>13</td>
<td>The total cable length between components and the intelligent node should be minimised.</td>
</tr>
<tr>
<td>14</td>
<td>The cables between each load sensor and the intelligent node should be equal in length.</td>
</tr>
</tbody>
</table>

These requirements have been decided based on several sources. Requirement 1-4 are strongly based on VCE’s TR concerning these areas. Requirement 5 should be specified by benchmarking similar products. The requirement specification concerning projectiles is an assumption based on a reasonable height of a standing bucket and weight of rubble managing to fall off and hit an E&E component in the frame. It has been added since it is a known risk that it could happen. Requirement 6 is based on the ICCS-module’s specifications. Requirement 7-11 are gathered from interviews with employees at VCE and aims to facilitate the work in the assembly. Finally, requirement 12-14 are based on the project directives and are relevant to what is aimed for by installing the ICCS-module in the first place.
4.1 Selection criteria

Based on the requirements, interviews, literature studies, etc. these criteria have been formulated to be used in the evaluation during phase 2.

4.1.1 Protective enclosure

These criteria are focused on the enclosure, not the placement directly.

- Sealing (including how the design influences the complexity of the seals)
- Damping
- Durability
- Cooling
- Placement (how well the design facilitates mounting and service of the node)
- Cost effectiveness (how many parts and how complex)

All of the criteria in this section are more or less directly taken from the requirements, except for the one concerning cost effectiveness. To include a cost requirement in Table 5 does not seem motivated since a cost limit or anything else in that fashion has not been formulated in this thesis. However, since it is highly relevant to formulate an opinion on whether the node is worth introducing from an economical perspective, it makes sense that it should be included in the evaluation process.

4.1.2 Placement of node

These criteria are focused on the placement.

- Sturdiness
- Protection from projectiles (e.g. placed behind an edge)
- Practicality of routing the cables
- Ease of holding in place while mounting
- Reachability (in terms of angle and crowdedness on the finished ART)

The first two criteria in this list can be adhered to requirement 5. The sturdiness is about how much the bracket and the location add to the resistance against mechanical forces and vibrations etc. It exists because it is not only the damping that makes a difference in these aspects. The practicality of routing the cables aims at avoiding solutions that requires pulling the cables on long de-tours. The two last criteria are there to try to take the work in the assembly into consideration since the factors that these two criteria represent are common problems when mounting and servicing components.
5 Concept generation

This phase will focus on generating a number of concepts for the enclosure and the placement to pick from during the next phase.

5.1 Protective enclosure

In this section functions for the enclosure will be identified. A number of concepts for each of these functions will then be generated. Some functions require excessive analysis with several candidates while others will be more straightforward with a small number of concepts. The concepts of each function will be combined into a number of complete concepts to be forwarded into the next phase.

5.1.1 Identification of functions

During the last chapter it was established what the ICCS-module should be protected against and also what it needs to deliver, but how should it be protected and be enabled to deliver? Some functions are easy to realise by looking at the requirements;

- Dust- and waterproof => Sealing
- Tolerate vibrations and shocks => Damping
- Pressure and humidity => Pressure and moisture ventilation
- Heat tolerances => Heat dissipation (or cooling)

Some are not as straightforward. With the product being an enclosure, the most obvious function seems to be to enclose the ICCS-module (a function referred to as “shell” from here on). What the function “shell” includes is not entirely obvious when considering the investigation into serviceability, which means that concepts making it possible to open and close the node for service are to be generated. It makes sense that this should affect the shell. For one, the shell should be open able, i.e. have a lid or be in parts, when considering this one might realise that something needs to hold these parts together. This leads to another needed function that will be called “joining of shell’s parts”.

Also - implicit but at the same time obvious - is that the ICCS-module needs to have cables connected to it, cables which will go through the enclosure connecting the inside to the outside. The function “cable ports” are therefore established as well. This is an area that is strongly related to the sealing, but at the same time is very much its own since it requires its own special parts and the placement is largely independent of other functions. Since the cable ports get their own group, their sealing will not be included in the “Sealing”-function.
5.1.2 The shell

Suggestions for the shell concepts were generated through brainstorming. Sketches of the results, along with brief descriptions, are listed below.

**Hood**
This concept simply consists of a flat base with an edge. The ICCS-module is fastened on the base and covered by a hood which overlaps the edge.

![Image of Hood concept](image)

*Figure 29 – The node is placed on a flat base and covered by a hood.*

- Practical to apply gaskets between hood and base’s edge
- Symmetrical and straight-forward, possibility to be made cost-efficiently
- Since it is split in two it could be hard to mount depending on which other concepts it is combined with.

**Kinder-egg**
Similar to the Hood-concept, but the lid and base is two halves of the shell being split on the middle. It might take some more working with the profile of the joint to adapt it to hold gaskets, screws, etc., than it would with the hood.

- Compared to the Hood, the durability is somewhat better since it is not so sensitive to shear forces acting on the top. This is because the arm of moment to the joint is shorter.
- Since it is split in two it could be hard to mount depending on which other concepts it is combined with.
Drawer
The shell consists of two parts of which one is a rectangular box with one face open. The other part is a “drawer” where the ICCS-module is mounted on a base; a wall seals the open face of the box when the drawer is inserted into the box.

+ Part off enclosure can remain while replacing the node
- More reliable sealing (better protected joints and only one surface in need of gaskets)
- More complicated profile (more complicated seals)

Cabinet
As the name indicates, this concept works like a traditional cabinet with a door that swings open on hinges. Alternatively, the “door” could be fastened to the machine and the “cover” could swing up instead.

+ Easier for service technician since door is mounted to box, i.e. less loose parts.
+ Simple design
- Requires a lot of space around it for door to swing up.
- Hard to seal around hinges
Enclosing and Mounting an Electronic Component on Articulated Haulers

Slot
Much like the Drawer-concept, but the box is instead pulled off of the base in this case.

+ Part of enclosure can remain while replacing the node
+ More reliable sealing (better protected joints)
− More complicated profile (more complicated seals)

Hatch
Consists of a base with and edge and a single wall on which the ICCS-module is mounted. A lid is rotating around the base-wall.

+ Easier for service technician since lid is mounted to box, i.e. less loose parts.
+ Leaves a lot of space for working with the ICCS-module during assembly and service
− Requires a lot of space around it for lid to swing up.
− Hard to seal around hinges
− A lot of areas in need of sealing

Figure 32 – Opens like a traditional cabinet.

Figure 33 – The shell is pulled off of the node and its base.
Completely moulded

The module and its enclosure could also be “moulded together”, i.e. it will not be possible to open at all. This could be performed by producing a case with one side open through which the component would enter. The open side would then be covered by a “lid” which would be welded to the rest of the enclosure. In this case everything will be exchanged, enclosure and all, if anything is in need of service or if anything needs to be added to the ICCS-module. This might of course be wasteful concerning cost and environment, but brings benefits when it comes to the sealing, the joining of the parts, and - to some extent - the protection from damage since it will be easier to make it sturdy. The only contact with the interior of the enclosure would be through the ports and the pressure vent.

Alternatively, in the case of potting compounds, it might be possible to simply fill the enclosure thereby practically making the ICCS-module and enclosure into one piece. Assuming the potting compound can resist the expected chemical loads; the lid could be skipped as long as the potting compound-side is mounted against a flat surface, or otherwise properly protected.

- Great sealing properties
- Durable
- Relatively low production costs
- Does not facilitate service
- Has to be thrown away if ICCS-module breaks or needs to be altered otherwise

Figure 34 – The greater part of the shell swings up from the base.

Figure 35 – The enclosure is completely moulded except for the hole where the ICCS-module enters and the cable ports
5.1.3 Joining of shell’s parts

Snap lock
A simple example can be seen in Figure 36. Locks automatically when the two parts are pushed together. Some mechanism would be needed to unlock all locking points simultaneously. Snap locks is a comparatively uncomplicated and low-cost method of locking.

- Locks automatically on closure, several locking points
- Low cost
- Hard to open conveniently

Figure 36 – (Thingiverse, 2016)

Screws/bolts
The parts can be joined together by either the same screws/bolts that are used to mount the node against the ART, or separate screws/bolts could be used (see Figure 37). The advantage of using separate screws/bolts is that the node can be opened without demounting it from the machine. Also, the screws/bolts can be of another model than the mounting screws/bolts, if desirable. By using the same screws/bolts, the design will most likely be simpler and more cost effective since it does not demand as many screws/bolts or holes in the node, neither does it demand the space and extra effort that would be needed to seal for these screws/bolts as well.

- Easy to apply the right pressure to seals
- Inconvenient to open and close, especially without electrical tools
Figure 37 – The screws that are joining the lid with the rest of the enclosure is not the same as the ones used to mount it. (PicClick, 2016)

Food box
Inspired from a storage container for food (Figure 38). One of the parts has flaps on all sides of it that folds down and snaps onto the other part, thereby locking on all sides while pressing the shell-parts against each other at the same time.

+ Simple design (few parts),
+ Several pressure points and the flaps automatically presses the lid against the gaskets (tighter)
+ Low cost
- Requires extra space on sides (less room for ports)

Figure 38 – Food container from Lock & Lock (2016)

Lever latch lock
A conventional diagonally cut locking bar that retracts when pushed against an edge, meaning that a key or other manual retraction method is unnecessary when locking. Inspired by the kind usually found on doors (Figure 39). Restrains the parts from sliding, but not from moving apart in the normal direction.

+ Locks automatically when shutting the lid
+ Same mechanism can lock at several points
- relatively complicated and expensive
Enclosing and Mounting an Electronic Component on Articulated Haulers

Figure 39 – (ASSA, 2016)

Hook Lock
Rotates out and latches onto a pin, etc. Also inspired by door locks (Figure 40). Restrains movements in all directions.

+ Restricts in all directions
- Relatively complicated and expensive

Figure 40 – (Tellmfg, 2016)

5.1.4 Sealing

Gaskets
See 3.6 for a guide on the gaskets of interest.

Potting compounds
See 3.8 for a guide on the potting compounds of interest.

5.1.5 Cable ports

The ports have to be sealed as well as the rest of the shell, which is why concepts for these must be carefully selected. If the cables are to connect on the inside of the shell, the connectors will simply be the standard connectors delivered with the node. The problem of sealing will be directed towards sealing around the cables where they enter though the shell. Another aspect of the ports are their placement, are they to be gathered on one side, or should they just be as close to their connection on the node as possible?

Pass-through (internal)

+ Easy to seal, no extra connectors (less parts)
- Problematic to mount
Figure 41 – The cable passes itself passes though the wall

Clasp (internal)

+ Easy to mount, no extra connectors (less parts)
- Problematic to seal

Figure 42 – The cable is removed more easily than in “pass-through”

Plug and play (external)
Cables are mounted so that they are automatically plugged into the node when the node is put in place.

+ Node can be replaced without affecting cables
- More complex suspension system since the “station” has to be fixed to the ART as well
- Cables have to be routed inside of enclosure

Figure 43 – The node is plugged into a ”station”
Enclosing and Mounting an Electronic Component on Articulated Haulers

**Standard (external)**

- Shortest possible distance from the connectors on the ICCS-module to the exterior ones
  - Inconvenient placement of exterior cables
  - Problematic sealing (more surfaces to seal)
  - More complicated shell (higher costs)

![Figure 44 – External ports are located as close to the internal ones as possible](image)

**Centralised (external)**

All ports on same surface.

- Convenient for exterior cables and design of shell
  - Have to route cables inside off enclosure

![Figure 45 – External ports are located at the same place](image)
5.1.6 Vibration and shock damping

This is an important function considering that the vibrations and shocks are quite heavy coming both from the engine, the movement of the vehicle when driving and the basket when it slams into the frame after tipping.

**Tied up**

One method to dampen the vibrations from the ART would be to suspend the node completely in an elastomer or something else with suitable properties so that it could swing freely inside the enclosure or – maybe in a more appropriate wording - so that the enclosure could swing freely around the node. This would make it a lot less dependent of the ART’s frequency and would dampen shocks effectively.

+ Very well dampened
  - Requires a lot of sway space
  - Hard to mount node inside enclosure

![Diagram](image)

*Figure 46 – The ICCS-module is tied up by something with spring characteristics (the springs are of a more symbolic nature)*

**Egg**

The node could be immersed in soft material, e.g. silicon or epoxy, which would then be enclosed by a shell, much like an egg with its hard shell and soft white. This would protect the node from direct hits, distribute the force over a larger area, and soften the following vibrations. The harder shell also protects the softer layer from being torn. This is also a kind of potting compound, like the concept presented in the sealing section. However, it will be assigned this name (“Egg”) for the sake of separating the two.

+ Well dampened
+ Works well with cooling and sealing ( 3 solutions in 1)
+ Protects cables inside shell
  - Service becomes limited, must replace damping together with ICCS-module
  - Higher cost than normal potting compounds
  - More complicated mounting procedure of module inside encapsulation
Enclosing and Mounting an Electronic Component on Articulated Haulers

**Figure 47 – The ICCS-module is surrounded by a dampening potting compound**

**Isolators**
It is common to dampen electronics by mounting them with isolators between the component and the mounting surface.

- Relatively low cost
- The ICCS-module itself does not need to be prepared with damping (can be mounted on the outside of the enclosure)
- Harder to damp in all directions

**Figure 48 – Example of an isolator for light weight equipment (Lord, 2016)**

5.1.7 Cooling

**External fan**
A small fan that pulls heat out of the enclosure (see Figure 49) through a waterproof hole. This would force the otherwise still air inside the enclosure to move, i.e. forced convection, instead of natural convection, which is less efficient. Having the fan connected to the outside also means that the cooling is not entirely dependent on heat being conducted through the walls. This would, of course, make the presented method of calculating the internal heat (see 3.4) invalid since it assumes natural convection.

- Effective cooling
- Hard to protect from damage
- Expensive
Passive  
By filling the enclosure with high velocity cooling medium the heat might dissipate faster from the node to the inside of the enclosure, than it would in air. This can be combined with heat sinks, which will maximise the outside area that is in contact with the outside cooling medium, which is the air in this case (see Figure 50).

- Protects from moisture, shocks and vibrations as well (less parts, lower cost)
- Effective cooling
- Service becomes limited, must replace damping together with ICCS-module
- Higher cost than normal potting compound
- More complicated mounting procedure of module inside encapsulation

Figure 49 – Example of a case with an external fan. (Itocorp, 2016)

Figure 50 – Module cooled by heat dissipating medium and a heat sink
Heat sink
An alternative to the “Passive” concept above would be to simply use heat sinks and exclude the high velocity cooling medium. It too can be illustrated with Figure 50 from the concept above.

+ Simple (low cost)
- Takes up a lot of space

5.1.8 Pressure and moisture ventilation

Apart from the pressure vents described in 3.7 above, no sufficient alternatives have been found for this function. The only other possible alternative would be to omit have a ventilation-function at all, but this is not advisable considering the amount of similar technology making use of these vents, it has also been recommended by an experienced engineer at VCE. This function will thus be put aside until phase 3, where an exact model of vent will be chosen.

5.1.9 Generation of complete concepts

To cover the solution space properly, a morphological matrix of functions and means to fulfil them was set up, the matrix is displayed in Appendix 3 - Morphological matrix on account of its vast size. The resulting concepts are presented in Table 6.

Table 6 – All generated combinations of the above presented concepts

<table>
<thead>
<tr>
<th>Concept</th>
<th>Shell</th>
<th>Joining</th>
<th>Sealing</th>
<th>Ports</th>
<th>Damping</th>
<th>Cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Hood</td>
<td>Snap locks</td>
<td>Striped gaskets</td>
<td>Standard</td>
<td>Isolators</td>
<td>Heat sinks</td>
</tr>
<tr>
<td>B</td>
<td>Kinder-egg</td>
<td>Same screws/bolts</td>
<td>Bulb extruded gaskets</td>
<td>Centralised</td>
<td>Isolators</td>
<td>Heat sinks</td>
</tr>
<tr>
<td>C</td>
<td>Hood</td>
<td>Same screws/bolts</td>
<td>Form-in-place</td>
<td>Centralised</td>
<td>Tied up</td>
<td>Heat sinks</td>
</tr>
<tr>
<td>D</td>
<td>Drawer</td>
<td>Snap locks</td>
<td>Bulb extruded gaskets</td>
<td>Plugg and play</td>
<td>Egg</td>
<td>Passive</td>
</tr>
<tr>
<td>E</td>
<td>Cabinet</td>
<td>Lever latch lock</td>
<td>Striped gaskets</td>
<td>Pass through</td>
<td>Isolators</td>
<td>Heat sinks</td>
</tr>
<tr>
<td>F</td>
<td>Slot</td>
<td>Separate screws/bolts</td>
<td>Striped gaskets</td>
<td>Plugg and play</td>
<td>Isolators</td>
<td>Heat sinks</td>
</tr>
<tr>
<td>G</td>
<td>Hatch</td>
<td>Hook lock</td>
<td>Form-in-place gaskets</td>
<td>Centralised</td>
<td>Isolators</td>
<td>Heat sinks</td>
</tr>
</tbody>
</table>
5.2 Placement

When considering the placement of the node some general rules has become apparent during phase 0 (see 3.1.6). Even though the point of this phase is to produce creative concepts while unhindered by critique, the reality that these rules emulate cannot be denied. This is why they will be used as a frame for the concepts presented.

**Concept 1: Horizontal corner**

All corners have two horizontal surfaces, one on the top and one in the bottom. There is a possibility that the node could be mounted directly to one of those. Presently, cables are routed in the upper front corner to the left (see Figure 51), which could offer a possibility to easily integrate the node with the cables. The front corner to the right is free from components. See Figure 51 below for a view if all the possible variants.
Concept 2: Vertical corner

Another possibility concerning the corners could be to use a bracket to get the node in a “standing” position. This might provide for other possibilities concerning cable routing and mounting. Notice that in Figure 52 below only one of the variants are shown since they are the same as the ones I Concept 1.

Concept 3: Bracket from upper ledge

A bracket could be fastened in the upper ledge, either through new holes or, possibly, by using the existing holes for the cable clams (Figure 53).
Concept 4: Alarm bracket

An idea is to fasten the node in the bracket holding the back-up alarm, after modifying it (see Figure 54). By adding a surface to the bracket that goes downwards, creating a T-shape instead of an L-shape, the node can be fastened in an already existing part.

To fasten it like this might save a lot of resources since it requires less development efforts, less material, and – eventually – one lesser article number, since this article...
would replace the original bracket. It is also a relatively reachable position on the finished ART, making it more practical for service technicians. However, an obvious problem in this case is the cable routing. The distance from the node to the load cells are far from equidistant and the node is placed far from many other components. Most of the cables going from the node to the components would have to go back through the main cable harness (see Figure 55). This would diminish - or even eliminate - the perceived benefits of having both shorter and less cables.

Figure 55 – The green line shows how the cables would have to go back though the main harness in the case of concept 4
6 Concept evaluation and selection

In this phase a few candidates from the concepts generated during phase 1 will be chosen for review. These candidates will be presented to both assembly staff and engineers whose input will hopefully help in avoiding unpractical solutions. The reviews will for one inspire modifications of the candidates, but also strongly influence the scoring process that will end the current phase.

6.1 Screening of the enclosure

Here the enclosure-concepts will be rated and reduced to a more manageable amount. The result can be found in Table 7 below, where concept B is used as reference. Each enclosure concept is judged after its potential to fulfil the criteria (e.g. a spherical node would have a low grade in respect to the placement criteria). The placement-concepts will not go through screening since they are already sufficiently few to be reviewed.

Table 7 – Screening of all the generated enclosure concepts

<table>
<thead>
<tr>
<th>Criteria\Concepts</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
<th>L</th>
<th>M</th>
<th>N</th>
<th>O</th>
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<td>0</td>
<td>+</td>
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<table>
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<th>Criteria\Concepts</th>
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<td>+2</td>
<td>+1</td>
<td>+3</td>
<td>+4</td>
<td>-2</td>
</tr>
</tbody>
</table>
6.1.1 How the screening was performed

The grade on each criterion for each concept is based on the accumulated presumed capabilities of all the part-concepts it is built up from, in comparison with the part concepts of the reference (concept B). The presumptions of the capabilities are somewhat declared in the advantages and disadvantages listed with each part-concept when they were presented in phase 1. The sealing criteria for concept A will be used to demonstrate on what presumptions the grading was performed.

- The enclosure-concept is “Hood”, whose the sealing properties are deemed to be equal to or somewhat better than those of the “Kinder-egg”; in this case the grade is considered a 0.
- Snap-locks are picked to join the enclosure-parts, which is okay from a sealing perspective since they tend to press the case, parts together, putting some pressure on the gaskets. At the same time they are not the most durable. They also tend to be placed at one or two spots only, which might not be enough to put an even pressure on the gaskets, especially not when it comes to the Hood-enclosure. This is why they were presumed to perform worse than the screws suggested for concept B.
- Striped gaskets will probably not seal as well as the bulb extruded gaskets in concept B, ergo, they to bring a minus to the sum.
- Standard placement of the cable ports are consistently considered less sealing than the centralised sealing since they are spread over a larger area, meaning that this also pulls down the grade.
- Isolators for damping are presumed not to affect the sealing abilities at all.
- A heat sink for cooling should not affect the sealing either.

All in all this sums up to a “minus-grade”, most definitely. This same reasoning was conducted with all criteria for every concept listed in Table 7. There is some cross-over effect between part-concepts that can make the effect they have on a criteria larger than the sum of both, i.e. stripped gaskets are presumed to make a bigger negative impact on the sealing if the enclosure is a “Hood” than if it is a “Drawer”.

As can be derived from the screening most concepts are leaning towards the positive side of the reference concept. However some concepts seem to fulfil the criteria to a greater degree than others, after some consideration concepts D, J, and O where chosen for further evaluation since they have the highest scores. To be noted is that these concepts only include the “Completely moulded” and “Drawer” within the Shell-function. However, concept G (Shell “Hatch”) was included as well to get a more diverse group of enclosures. Narrowing the choice down to only two Shell-concepts before they have been evaluated would be too soon, however suitable they seem.
6.1.2 Resulting concepts

This concept is made with serviceability in mind. The idea is that the “drawer”-part is easily detached from the rest of the “body”, being fastened only with snap locks that can be controlled via one or more switches. The node itself is dampened with potting compound and attached to the “drawer”-part in such a way that the node can be replaced with another one without hassle. The potting compound also serves as a cooling medium. The enclosure is fastened to the machine or bracket with screws/bolts.

This concept is sturdy and requires a smaller number of parts than any of the others. The downside is the serviceability and the cost for the thermally conductive potting compound needed for the cooling. If the ICCS-module should fail, the whole node has to be exchanged, enclosure and all.
This concept shares the Shell - as well as the serviceability - with concept D. The differences in this concept are the methods used for locking and damping. Also, the gaskets have been exchanged to the less expensive, but less sealing, stripped gaskets.

The ICCS-module is mounted on a base surrounded by a rotating latch (lid) which is locked by a hook lock. It is serviceable and has a reliable opening/closing function. However, because of the large contact area between the latch and the base, sealing is a challenge.
6.2 Assembly staff’s reviews

Two members of the assembly staff were interviewed concerning the concepts from the screening for both the enclosure and the placement. The concepts were explained orally with the aid of screenshots from a CAD-model (see below) and a very simple true-to-scale-model (Figure 60).

![Figure 60 – True-to-scale model situated on an ART](image)

6.2.1 Protective enclosure

Although none of the enclosures got negative criticism, the interviewees liked the idea of concept D and O, where they could mount the ICCS-module on the drawer and plug it into the enclosure which had been pre-mounted on the ART. Mainly because it would be easier to mount the shell and it’s bracket to the ART with the module-part not being there. The most important quality for an enclosure seemed to be that the ports were pointed in the most convenient direction and that it was easy to plug them in.

6.2.2 Placement

All of the placement-concepts listed above were introduced to the interviewees. Some refinements were made after getting insights into what would work and what would not. The concept where therefore reduced to one variety each after these interviews.
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As described earlier – albeit not highlighted, the cables that go from the ECU at the driver’s cabin all the way back to the components in the load unit does so in one piece. An unexpected benefit of having to split the cables between the ECU and the components would be that it could make work easier for the assembly staff. The cables have to be attached to the machine after the components have been mounted to the ART, it would therefore be a great improvement if each components cables could be attached to the component when they were mounted, and later plugged into the node. This is especially true for the components on the axels of the smaller ARTs (A25-A30) which has to be installed when the axels are already mounted to the frame. This requires uncomfortable working positions and takes more time than necessary. It could be mentioned that this modularity would be very valuable on the FS-ARTs as well since the installation of the heavy and bulky suspension hydraulics (Figure 62) module would be made more efficient if cables to the E&E could be attached to it before mounting.

Figure 61 – The placements left after the assembly staff’s review
Concept 1
Good reception from the interviewees, although they were concerned with the ports directions.

Concept 2
This was the best received of all the concepts presented since it is believed to be an unproblematic position when installing other components. It is also practical because it works well with the wish to keep cables going from the node to the components short, and the wish to keep cables to the load units equal since it is approximately in between the load units. Another argument speaking for this placement is that there already is a “fork” where the cables split into two main bundles, placing the node here would mean less “de-tours” for the cables where they have to go back to the “fork” because their component is in the other bundle (see Figure 55). This situation would be more or less unavoidable in the case of concept 3 or 4 below.

Concept 3
This concept did not receive any praise or critique other than that it will be troublesome when installing the mentioned suspension hydraulics (Figure 62).

Concept 4
Concept 4 were not seen as a good alternative by the interviewees in the assembly since both the central lubrication system and the hydraulics for the underhung tailgate (Figure 63) takes up a lot of space in this area when they are present. I.e. heavy modifications would be necessary to make this alternative viable.
6.3 Engineer's reviews

The scoring was performed by letting engineers within hardware and design at VCE fill out a query in which they could grade each concept selection criteria on a five graded scale and leave an optional comment (Appendix 2 - Query (Swedish)). The results will be taken into account when deciding the final score. This was done after interviewing the assembly staff which is why the concepts presented to this group were the more viable candidates presented in Figure 61 above. To not risk the recipients of the query getting overwhelmed with information but still be able to give valuable answers, the description and models provided were kept on a reasonable level. Reasonable being defined as somewhat less detailed then what has been described so far in this thesis. The most prominent examples of this were that the enclosures selection criteria “Cooling” and the placement criteria “Ease of holding in place (…)” as well as “Reachability” were removed in the query. Another modification is that the cable ports were not described.
Concept D

This concept was scored as moderate in some criteria and poor in some. Overall, the weakest point was the damping (see Table 8). The respondents had a completely different opinion concerning the damping quality of the potting compound vs. the isolators than what the author had perceived. Comments concerned the complexity of the construction, both from the aspect that it might not be functional after five years of operation or more, and that connecting cables might be a hassle with the closing-function. Also, vibrations between the drawer and the box-part, damaging the insulation upon closing as well as the sturdiness of the snap-locks were points of concern. An ability to lower costs from time spent in assembly and service were somewhat recognised however. What is more, a point made by one respondent was that a lock that actively presses the lid against the gasket would be preferable.

Table 8 – Mean scores for concept D

<table>
<thead>
<tr>
<th>Selection criteria</th>
<th>Mean score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sealing</td>
<td>2.5</td>
</tr>
<tr>
<td>Damping</td>
<td>2.5</td>
</tr>
<tr>
<td>Durability</td>
<td>2.75</td>
</tr>
<tr>
<td>Placement</td>
<td>3.25</td>
</tr>
<tr>
<td>Cost</td>
<td>3.25</td>
</tr>
</tbody>
</table>

Concept J

Concept J was held high by most because of its simplicity and sturdiness (see Table 9). As with concept D, damping was a concern. The lack of serviceability and the possibility of it being troublesome to mount were also commented upon, although opinions were split as to whether service will be needed for this component.

Table 9 – Mean scores for concept J

<table>
<thead>
<tr>
<th>Selection criteria</th>
<th>Mean score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sealing</td>
<td>4.75</td>
</tr>
<tr>
<td>Damping</td>
<td>3.5</td>
</tr>
<tr>
<td>Durability</td>
<td>4</td>
</tr>
<tr>
<td>Placement</td>
<td>3.5</td>
</tr>
<tr>
<td>Cost</td>
<td>3.5</td>
</tr>
</tbody>
</table>
Enclosing and Mounting an Electronic Component on Articulated Haulers

Concept O
Not unexpectedly the ratings were similar to concept D. The main differences – as can be seen in Table 10 - are in damping and durability because of the change to isolators and a lever latch lock. Some respondents acknowledged that the changes might also mean higher costs.

Table 10 – Mean scores for concept O

<table>
<thead>
<tr>
<th>Selection criteria</th>
<th>Mean score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sealing</td>
<td>2.25</td>
</tr>
<tr>
<td>Damping</td>
<td>3.5</td>
</tr>
<tr>
<td>Durability</td>
<td>3</td>
</tr>
<tr>
<td>Placement</td>
<td>3.5</td>
</tr>
<tr>
<td>Cost</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Concept G
Received relatively high ratings overall, but sealing, durability and cost were assigned very low scores in some cases which - as Table 11 shows - had a strong effect on the mean. This goes especially for sealing since the sealing areas are many and complicated. Positive comments were received concerning assembly, vibration between parts and maintenance.

Table 11 - Mean scores for concept G

<table>
<thead>
<tr>
<th>Selection criteria</th>
<th>Mean score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sealing</td>
<td>2.5</td>
</tr>
<tr>
<td>Damping</td>
<td>3.75</td>
</tr>
<tr>
<td>Durability</td>
<td>2.5</td>
</tr>
<tr>
<td>Placement</td>
<td>4.25</td>
</tr>
<tr>
<td>Cost</td>
<td>2.25</td>
</tr>
</tbody>
</table>
6.3.1 Placement

**Concept 1**

This concept got high scores, but each selection criteria were rated in the mid/low range in at least one review which pulled the means displayed in Table 12 down somewhat. One comment concerns which side the ports are going to face, saying that they should be facing downwards for the best protection against dirt and moisture, which will be hard to achieve in this concept. Another comment mentions that the horizontal position will be more subjected to liquids accumulating under the bottom, heightening the risk for short circuits, especially in spring time when temperatures are highly fluctuating. Another complaint was that the cable routing is a bit problematic since cables would have to be fastened somewhere when going down to the node and up again. On the topic of service/maintenance, one respondent pointed out that reaching the node on a fully assembled machine out in the field might be a bit of a hassle. It would require tipping the bucket and setting up the safety-support so that it does not fall down while people are below it. The service technician would then have to climb onto load unit and replaced the node from above. If the node is to be positioned in this manner, it will have to be designed with this in mind.

![Table 12 - Mean scores for concept 1](image)

Concept 2

Although similar to concept 1, this concept got higher scores overall (see Table 13), only the cable routing can be considered to be in the medium range. One respondents commented that it were better than concept 1, but not optimal, another that it was the best available.

![Table 13 – Mean scores for concept 2](image)
Enclosing and Mounting an Electronic Component on Articulated Haulers

Concept 3
This one received relatively low scores in both sturdiness and protection from projectiles, the cable routing were much higher in the majority of responses though (see Table 14). Vibrations were a concern both in that the bracket is hanging from an edge which puts it at risk of coming into resonance with the ART’s vibrations all too easily. Also, having the main cable harness right behind the bracket might not be a good idea since they might be damaged by the vibrations. Also, EMC-related problems might be a risk here since the ground plane is too small to diminish disturbances.

Table 14 - Mean scores for concept 3

<table>
<thead>
<tr>
<th>Selection criteria</th>
<th>Mean score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sturdiness</td>
<td>2</td>
</tr>
<tr>
<td>Projectile protection</td>
<td>3.5</td>
</tr>
<tr>
<td>Cable routing</td>
<td>4</td>
</tr>
</tbody>
</table>

Concept 4
As can be seen in Table 15, concept 4 got medium scores overall, where the sturdiness is the main reason for the score being pulled down. The EMC- and vibration problems are as present in this concept as they were in concept 3, but the belief in its potential to become a good concept with some modifications is clearly higher.

Table 15 – Mean scores for concept 4

<table>
<thead>
<tr>
<th>Selection criteria</th>
<th>Mean score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sturdiness</td>
<td>2.5</td>
</tr>
<tr>
<td>Projectile protection</td>
<td>3.75</td>
</tr>
<tr>
<td>Cable routing</td>
<td>3.75</td>
</tr>
</tbody>
</table>
6.4 Modifications

After reviewing each concept it has become clearer how each of them can be improved. Concepts with potential to be much improved with small changes are modified below.

6.4.1 Enclosure

Concept J
To heighten the damping, isolators and a welded lid will replace the potting compound’s dampening, sealing and heat dissipating properties (practically making it the same as concept H from above). It is hard to approximate how this will affect the cost criteria, but a somewhat lower value will be used when calculating the final scores. The cooling will likely be less sufficient without a potting compound, which - depending on the enclosures final dimensions – might have to be compensated for by enlarging the heat sink. This will take up more space, but it should not be enough to make a large impact on the ART’s design.

Concept O
Screws/bolts instead of locks to lower costs and to press the lid against the gasket, although not as elegant, might be the most sufficient way of making this a more competitive concept.

Concept G
By simplifying the lid to have less area in need of sealing the cost- and sealing score would be noticeably improved.

6.4.2 Placement

Concept 2
Mainly, Concept 2 was well protected and had a sturdy mount and generally a good position for the cable routing since it is close to the “fork” in the main harness. The problems are that it is mounted too low and out of reach for technicians. A modification to fix this could be to weld it to the wall of the frame closer to the main cable harness.

Concept 4
A potential solution for the resonance and the reachability as well as the space-issue could be to mount the node on the horizontal surface right beside the alarm, instead of below it. This will still be problematic on ART’s with underhung tailgates (see Figure 63). A custom solution for the few machines actually using this option might have to be considered.
6.5 Final scoring

In Table 16 each concept will be scored. The means of the scores from the engineer’s reviews, their comments and the input collected from the assembly staff will have heavy influence on these final scores. They will be adjusted against the factors not included in the query or the reviews, such as the cooling criteria and the type of gasket. These could be referred to as a cumulative score of all input and facts collected for each concept this far. The maximum score is 150 for the enclosures and 125 for the placements.

Table 16 – Final scores for each of the concepts

<table>
<thead>
<tr>
<th>↓Criteria\Concepts→</th>
<th>Weight</th>
<th>D</th>
<th>J</th>
<th>O</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sealing</td>
<td>5</td>
<td>3.5</td>
<td>4.75</td>
<td>3.75</td>
<td>3.5</td>
</tr>
<tr>
<td>Damping</td>
<td>5</td>
<td>2.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Durability</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>3.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Cooling</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Placement</td>
<td>3</td>
<td>3.25</td>
<td>3.5</td>
<td>3.5</td>
<td>4</td>
</tr>
<tr>
<td>Cost effectiveness</td>
<td>4</td>
<td>3.25</td>
<td>3.25</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>69.75</td>
<td>89.75</td>
<td>84.25</td>
<td>81.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>↓Criteria\Concepts→</th>
<th>Weight</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sturdiness</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Projectile protection</td>
<td>3</td>
<td>3</td>
<td>4.25</td>
<td>3.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Cable routing</td>
<td>4</td>
<td>3.5</td>
<td>4.5</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Ease of holding in place</td>
<td>2</td>
<td>5</td>
<td>4.5</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Reachability</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>56</td>
<td>65.75</td>
<td>44.5</td>
<td>59.5</td>
</tr>
</tbody>
</table>

As can be seen, concept J and concept 2 got the highest scores in their respective groups. These are the concepts that will be designed in detail in the upcoming last phase.
7 Detail design

This phase begins abruptly with a section presenting the first version of the final enclosure concept and each of its parts as well as the placement. In the following sections each part and each design issue will be treated in detail as a “focus area”. The enclosure and placement will be updated if the need for it is discovered in a focus area, which is why its appearance will change successively as the phase proceeds.

7.1 Initial design of the parts

With the chosen concept for placement, as mentioned before, the node might have to be replaced by a technician working from the top of the load unit. After some consideration the concept in Figure 64 below seemed to fit for the circumstances well. It is relatively simple in its design. It can be removed from its bracket from above by loosening four nuts. The cable connectors are to be placed in the lower end of the enclosure, facing downwards, as was recommended by a respondent during the engineer’s reviews (6.3.1)

![Figure 64 – A first look of the final enclosure concept, with brackets](image)

7.1.1 Cable connector cover

The cable connectors need to be protected from physical tearing, a necessary function which was realised late into the process. It exists on the before mentioned IMU among other components, which is why it is assumed necessary in this case as well. A cover for them has therefore been designed to attach to the rest of the enclosure. It has been made with respect to the already established design specifications. This cover will surround the cable connectors on all sides. It is fixed to the enclosure by sliding into a slot and having screws go though it into the holes in the node (Figure 65). The inclusion of this “slot and rib”-mounting is done to assure that the cover will be properly fixed to the
Enclosing and Mounting an Electronic Component on Articulated Haulers

node, but also so that it will be easy for the assembly personnel to keep the cover in place while fixating the screws.

![Diagram](image1.png)

**Figure 65 – The cover. Holes for the cables can be seen in the upper right figure.**

As can be seen in Figure 65 the cables will exit the enclosure on the side that is facing the ART’s frame. This is believed to be the most protected spot in the enclosure’s exterior, both in respect to object that might exert force on the cables and from high pressure streams of water.

7.1.2 Fixating the ICCS-module

Holders will be necessary to fix the ICCS-module inside the enclosure. They will work by having four taps in the base surface box that goes through each of the existing holes in the module and then meets holes in the lid (see Figure 66).
The holders will have flanges that presses against the module, making sure that it will not move after the lid has been welded on. Since the force exerted on the node by the holders is stopped when the top of the taps meets the bottom of the holes there is little room for margins when producing these features. It is therefore advisable to make them somewhat smaller, and make up for the empty space, by placing a cushioning material on the end of the taps as well as on their flanges, see Figure 67 for an example, note that these cushions would only be needed on either the “bottom”- or “lid”-holders, not both.

Figure 66 – Various illustrations of the holders

Figure 67 – Cushioning material on the "bottom"-holder
7.1.3 Bracket

The bracket consists of two parts which are quite simple in design. They are welded to the frame and support two isolators each.

7.1.4 Measurements

The measurements below are of course to be taken lightly. They are only preliminary “reasonable” values based on the nodes measurements defined for the purpose of having something to base the calculations and designs in the upcoming sections. The measurement might be subjected to change during these sections. The directions used from here on are defined in Figure 68 and the preliminary measurements are to be found in Table 17.

Table 17 – Preliminary measurements

<table>
<thead>
<tr>
<th>Measured object</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Protective enclosure</strong></td>
<td></td>
</tr>
<tr>
<td>Mass</td>
<td>570 g</td>
</tr>
<tr>
<td>Wall thickness</td>
<td>5 mm</td>
</tr>
<tr>
<td>Length</td>
<td>150 mm</td>
</tr>
<tr>
<td>Height</td>
<td>105 mm (142 mm with cable cover plate)</td>
</tr>
<tr>
<td>Width</td>
<td>40 mm</td>
</tr>
<tr>
<td><strong>Length between module-holders</strong></td>
<td>102 mm (specified by ICCS-modules datasheet)</td>
</tr>
<tr>
<td><strong>Height between module-holders</strong></td>
<td>62 mm (specified by ICCS-modules datasheet)</td>
</tr>
<tr>
<td><strong>Length of connector space</strong></td>
<td>132 mm</td>
</tr>
<tr>
<td><strong>Height of connector space</strong></td>
<td>26 mm</td>
</tr>
<tr>
<td><strong>Width of connector space</strong></td>
<td>37 mm</td>
</tr>
<tr>
<td><strong>Cable cover</strong></td>
<td></td>
</tr>
<tr>
<td>Mass</td>
<td>124 g</td>
</tr>
<tr>
<td>Wall thickness</td>
<td>3 mm</td>
</tr>
<tr>
<td>Length</td>
<td>150 mm</td>
</tr>
<tr>
<td>Height</td>
<td>40 mm</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Mass</strong></td>
<td>790 g (module included)</td>
</tr>
</tbody>
</table>
7.2 Position

The node should be positioned vertically (Figure 69) to minimise the risk of being hit by projectiles. As mentioned in phase 2, welding a bracket against the vertical walls of the ART’s frame seems to be the best option to get the node stable and close enough to the cable harness and the upper edge.

7.3 Manufacturing techniques and materials

A suitable manufacturing technique for the enclosure could be sand casting. Considering that the expected production volumes to be in the medium range, it might not be profitable to invest in the die needed for die casting. Something else talking to the favour of sand casting is that the enclosure has a flange at the opening where the ICCS-module enters that would be problematic if die casting were to be used (see Figure 70). The material to be used in the coming calculations is Aluminium 356.0-T6 Sand Cast.
The cable connector cover and the lid could be produced by casting as well. The brackets have a simple and symmetric profile and are also completely flat, meaning that the easiest method to make them is probably to cut them out from a sheet with the right thickness and drill the holes by hand. The brackets should be in the same material as the rest of the frame. The lid is also quite simple. It only consists of two features; a 5mm thick plate covering the hole for the node exactly, and an edge around this plate that is to be welded to the outside of the enclosure.

### 7.4 Pressure venting

Although a specific product is pointed out in this section, the intention is not to specify an exact product for VCE. It is only done to show that there are protective vents readily available on the market that will satisfy the intended use in this node, and if a vent is to be chosen in the future, it should have characteristics similar to the one specified here.

The valve that has been chosen is believed to have appropriate specifications for this application. The considered vent can be seen in Figure 71 and belongs to Gore’s automotive vent series, it is specifically recommended by Gore to be used in electronic control units. It is mounted to the enclosure wall with a snap lock.

---

**Figure 70 – A cross cut of the enclosure showing the problematic flange**

**Figure 71 – Polyvent standard series AVS 14 (Appendix 4 – Pressure vent’s data sheet)**
Detail design

The vent fulfils all the environmental requirements that are put upon the rest of the enclosure (see Appendix 4 – Pressure vent’s data sheet). It should be noted, however, that the IP-level is at IP68 but is claimed to be able to reach IPX6K and IPX9K depending on housing geometry, what this implies is not explained. The minimum airflow is said to be around 15 l/h at 7kPa, which should be enough for the node’s specified volume. In Figure 72 the Catia-model from above were updated with a dummy of the suggested vent. The vent were placed on the top of the enclosure to allow heat to escape optimally, but other placements might fit better, to place it on the lid on the back is a lot more protected from high pressure streams after all.

![Figure 72 – The pressure vent mounted on the enclosure](image)

7.5 Cable Connectors

The number of connectors mounted here may vary depending on how modular one wants the cable harness to be, e.g. if the cables going between the node and the wheel axles is to be modular, one connector per axle will be needed (touched upon in 6.3.1). This means that the number of connectors could be subject to change if the cable harness is to be made more modular. Another concern is that the connectors should be living up to the IP-requirement that the rest of the enclosure has. However, with the cable cover keeping the connectors from direct hits of high pressure streams, a rating of IP68 (extended immersion) for the connectors should be enough for the connectors and the cover to reach both IP66K and IP69K when combined.

Several suitable models of connectors were found that should live up to all the requirements. The challenge with the connectors is not so much to find a good one as it is to find room for one that lives up to the IP-requirement. Those found that are classified as at least IP68 are all very bulky, and since breaking the requirement is no option, the enclosure will have to be redesigned to make room for these. This is somewhat problematic since the centre of gravity is highly dependent on the width in the current design to avoid “wobbling” (this is covered further in 7.6). Changing the length also affects the enclosure a lot since it has big implications for the total volume of both the enclosure and the cable cover’s measurements as well. The height of the enclosure could have to vary as well, but this does not have as great implications on the design as the length and width.
Another decision to make is how many connectors there should be. Since the decision on what to make modular or not is not within the scope of this thesis this will not be treaded to any great extent, and an exact model will not be recommended.

The size of the connectors comes down to the number of positions, or pins, that a connector has. The ICCS-module has 64 positions all in all, meaning that the connectors will have to amount to at least this sum, but more than 64 are acceptable. In Figure 73 two possible connectors are displayed.

![Connector Diagram](image)

**Figure 73 – To the left: A connector from Tyco’s Deutsch with 12 positions**
**To the right: E connector from Molex with 80 positions**

The connector from Tyco only has 12 positions and might work well for the modular application mentioned above. The Molex-connector has as many as 80 positions. Overall, it is hard to say how much larger the enclosure will have to be since it depends on the chosen connector, but it does seem very probable that some expansion will have to be made of the space intended for the connectors. In an attempt to take this into account, the enclosure’s width can be expanded to 60mm. To create more room for the connectors the design of the cable cover were modified so that the space-consuming slot were placed in the lower end instead (Figure 74).
The consequences that the changes had on the measurements can be seen in Table 18. Some other changes were introduced as well for reasons that will be explained in 7.6.

**Table 18 – The updated measurements (the not listed ones are the same)**

<table>
<thead>
<tr>
<th>Measured object</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Protective enclosure</strong> (* = applicable for other parts as well if nothing else is specified)**</td>
<td></td>
</tr>
<tr>
<td>Mass</td>
<td>703 g</td>
</tr>
<tr>
<td>Width</td>
<td>60 mm</td>
</tr>
<tr>
<td>Length of connector space</td>
<td>144 mm</td>
</tr>
<tr>
<td>Height of connector space</td>
<td>31 mm</td>
</tr>
<tr>
<td>Width of connector space</td>
<td>57 mm</td>
</tr>
<tr>
<td><strong>Cable cover</strong></td>
<td></td>
</tr>
<tr>
<td>Mass</td>
<td>112 g</td>
</tr>
<tr>
<td>Width</td>
<td>58 mm</td>
</tr>
<tr>
<td>Rib Height</td>
<td>3 mm</td>
</tr>
<tr>
<td>Rib Width</td>
<td>3 mm</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
</tr>
<tr>
<td>Mass</td>
<td>1099 g (module and lid included, brackets and isolators excluded)</td>
</tr>
</tbody>
</table>
7.6 Damping

Since the isolators are going to be subjected to great amounts of water mixed with rocks and grain, high and low temperatures as well as occasional hits from projectiles in varying directions, i.e. they need to be on the sturdier side.

7.6.1 Isolator model

One isolator model that might stand as an example is the HT0-1, a broad temperature range mount from LORD, a manufacturer of isolators. The datasheet can be seen in Appendix 5 – Isolator datasheet. The isolator has the advantage of being inside a “cup” of metal shielding the elastomer from being torn. Another upside is that the intended application is vehicles driving in rough terrain. It is made to provide damping in all directions and to be very tolerant to temperature variations. A problem with the isolator is that the vibrations- and shock-tests performed on it is not as strict as the ones required at VCE, meaning that it would have to go through testing before the requirements on vibrations and shocks can be verified. The isolator’s hole is threaded according to the UNC standard with a size of #8-32 UNC-2B THD X, which means that it has a major diameter of 4.1656mm which is much smaller than then the M8 that VCE commonly uses for their mounts.

Figure 75 – Cross section and 3D view of a typical installation of the HT-series (Lord, 2016)

7.6.2 Placement of isolators

In 7.5 it was mentioned that increasing the width also increases the risk of “wobbling” this is because the fastening point between the brackets and enclosure were located at the end of the enclosure width-wise (see Figure 68). The problem with placing the centre of gravity further out from the brackets is that it then moves away from the
elastic centre located there (see Figure 76) which means that the shear forces on the elastic centre will increase.

![Image of node in profile with elastic centre and centre of gravity]

**Figure 76 – Node in profile with elastic centre and centre of gravity**

To account for this the fastening points for the isolators were moved towards the centre of gravity. To further improve the design in this sense, the fastening points were moved down (Figure 77), something that was not allowed before modifying the design.

![Image of fastening points in outer corners]

**Figure 77 – The fastening points for the isolators now in the outer corners. The isolators have been added as well.**
7.6.3 Calculations

The HT0-1 is specified for a nominal axial frequency of 22Hz, but the actual natural frequency of the system depends on the static load that each isolator will carry.

\[ f_n = f_{nn} \times \sqrt{\frac{P_R}{P_A}} = 22 \times \sqrt{\frac{0.45}{0.252}} = 29.4 \text{ Hz} \]

This means that the natural frequency will not be avoided in the tests which begin at lower frequencies. The best case would have been to avoid it, but hitting it does not mean that the system will not pass the test. The datasheet for the node lists the highest transmissibility at the natural frequency \( T_{max} \leq 3.5 \) (at 148°C) which is quite low in comparison to many other isolators (up to 10 is common). This makes the situation somewhat better.

With the natural frequency known, we can calculate the frequency that marks the lower limit of the isolation region:

\[ f_d \geq f_n \times \sqrt{2} = 41.6 \text{ Hz} \]

So after 41.6 Hz the isolator starts protecting the node from vibrations.

The horizontal natural frequencies can be found with the spring coefficients found in the datasheet and the theory presented in 3.5.3.

\[
\begin{align*}
R &= \frac{K_H}{K_V} = \frac{10}{9} \approx 1.11 \\
H &= \frac{142}{150} \approx 0.9
\end{align*}
\]

\[
\begin{align*}
\frac{f_{n,M1}}{f_{vert}} &\approx 0.65 \\
\frac{f_{n,M2}}{f_{vert}} &\approx 1.91
\end{align*}
\]

\[
\begin{align*}
f_{n,M1} &= 0.65 \times 29.4 \approx 19.11 \text{ Hz} \\
f_{n,M2} &= 1.91 \times 29.4 \approx 56.15 \text{ Hz}
\end{align*}
\]

This means that the node is in the isolation zone after around 56 Hz when vibrating horizontally. As for the shock transmission and deflection, the calculations cannot be declared without revealing exact test figures from Volvo’s TRs, but it was concluded that the deflection of the isolator when subjected to the VCE’s tests is enough to make it hit the bottom of the isolator, i.e. the node will be dampened during the shock.
7.7 Fastening elements

As mentioned in 7.6.1 the hole of the damper is of the standard #8-32 UNC-2B THD X and has a diameter of 4.1656 mm. To make demounting – and hopefully mounting as well – easier headless screws could be fastened in the isolator onto which the node could be placed and fixed with washers and nuts (Figure 78).

![Figure 78](image)

*Figure 78 – The node fastened in the isolators.*

The screws fastening the cable cover will not have to withstand the same forces as the ones holding the node to the isolators, which is why they can be smaller. They should be countersunk to not stick out from the cable cover (Figure 79). The screws could be the same as the ones used to fasten the isolators to the brackets since they both are going to be countersunk. If they cannot be the same, it is still important that the same tool can be used on them so that assembly and demounting does not become unnecessarily complicated.

![Figure 79](image)

*Figure 79 – Countersunk torx-screws (Champion parts, 2016)*
7.8 Thermodynamics

In this section the effects of temperatures on the enclosure and the ICCS-module will be examined. Calculations will show if the design so far holds up to the temperature requirements or if – and if so what – changes need to be made.

7.8.1 Cooling

To see if the current design of the enclosure is sufficient to cool the ICCS-module, a worst-case-scenario will be set up. Assuming that there is no heat sink and the node is working at full load, there is no forced convection on the outside and that the extra ventilation from the pressure valve is not included. Add to this that the outside ambient temperature $T_e$ is about $45^\circ C$. What is the calculated internal air temperature $T_i$ during these conditions?

First the ICCS-modules heat dissipation $Q_{\text{worst}}$ at full load needs to be found. Since the outgoing voltage is not listed in Appendix 1 – ICCS-module’s datasheet this is hard to do according to the formula in 3.4. However, thanks to the worst case scenario being assumed, it is still achievable. In the absolute worst case, the ICCS-module would convert all the power put into it into heat, meaning that the worst case $Q_{\text{worst}}$ could be found by simply setting $V_{\text{in}} = 0$ and using the “current consumption” as $I$ and the supplied voltage $V_{\text{supply}}$ as $V_{\text{in}}$ in the power equation. According to Appendix 1 – ICCS-module’s datasheet $V_{\text{supply}}$ may be chosen to be in between 9 and 30 volts. Assuming that the maximum voltage is chosen then the worst case scenario heat dissipation would be the following:

$$Q_{\text{worst}} = \Delta P_{\text{worst}} = (V_{\text{supply}} - 0) * I = 30 * 0.070 = 2.1 \text{ [W]}$$

The calculations from 3.4 can now be applied together with the material data and the enclosure’s measurements. As for now, we only have the areas and the thermal coefficients, meaning that the thermal resistances cannot be calculated until we find the temperatures $T_{es}$, $T_{is}$ and $T_i$, as was predicted in 3.4.

Finding the external surface temperature $T_{es}$

By inserting the values we have into equation (12) and using the “Goal seek”-function in Microsoft Excel to satisfy the equation by varying the surface temperature we find that the value below satisfy the other conditions.

$$T_{es} \approx 322.45\ K \ (49.45^\circ C)$$

\[\text{---}\]

2 The areas used in these calculations are, in fact, based on the measurements seen in 7.1.4. The calculations were not made again after the measurements had changed since an increased area would only lead to a better result, which is why the author finds this behaviour defendable.
Finding the internal surface temperature $T_{is}$

Using equation (14) we can determine the internal surface temperature $T_{is}$:

$$T_{is} = R_{cond}Q + T_{es} = 0.0008 \times 2.1 + 322.45 \approx 322.45 \, K \quad (49.45^\circ C)$$

As can be seen, the conduction makes little difference; this is to be attributed to the thin of the walls.

Finding the internal air temperature $T_i$

Again using the “goal seek”-function to find the sought after temperature, this time by inserting the known values into equation (15) and solving for the internal air-temperature we find that

$$T_i \approx 328.71 \, K \quad (55.71^\circ C)$$

The result indicates that the internal air temperature should be below the required temperature of 85°C. Considering that the calculations are based on the absolute worst case scenario regarding the ICCS-module's heat dissipation and the outside ambient temperature were set to a high value, the real temperature is expected to be at this value or lower.

A factor that might affect the result is that the bottom surface of the enclosure will be inside the cable connector cover and therefore the convection to the ambient air will not work as predicted there. This uncertainty can be controlled for by simply setting the thermal resistance for the bottom part to something very big (10^9 in this case). This gives us the internal air temperature:

$$T_i \approx 329.95 \, K \quad (56.95^\circ C)$$

This differs so little from the previous value that the effect of the radiation can be deemed negligible in this case. However, it can also be argued that the emissivity coefficient might be lower in reality (now set to 0.82), which also would heighten the approximated temperature. To control for the emissivity coefficient at lower numbers we could exclude its effect on the equation in the same manner as with the bottom surface resistance, i.e. setting the radiation thermal resistance to a large number, meaning that the radiation will not contribute at all to the cooling. Alternatively the emissivity coefficient can be set to 0. Running the calculations again results in the internal air temperature:

$$T_i \approx 338.0 \, K \quad (65.0^\circ C)$$
This change had a notably larger impact on the result. However, the temperature is still 20°C below the threshold of 85°C. This means that the ICCS-module should be able to function in most high-temperature conditions without a heat sink, but it should be noted that this does not mean that the module’s life-time cannot be extended by introducing one.

### 7.8.2 Thermal expansion

As the surroundings vary in temperature, the measurements of the enclosure will vary as well. This will put strain on both the ICCS-module being fixed by the holders to the enclosure and the cable connectors. To get a notion of whether any of these are at risk because of this phenomenon, some simple calculation can be performed using the thermal expansion coefficient of the material 356.0-T6. As before, calculating what would happen in the worst case scenario is a good point to start at. The worst case would be the contraction that occurs at the coldest allowable temperature of -40°C. The difference in length is proportional to the temperature difference from the room temperature (the temperature at which the parts were manufactured, presumably around 20°C). This is why this cold scenario is worse than the hot scenario described in the above section since the temperature difference is a lot larger (|ΔT'| = 60°C compared to 25°C). This is, of course, assuming that contraction is as damaging as expansion to the parts at risk.

In our case we are interested in the difference in both length and height between the module’s holders. We would also like to see how much the cable connectors’ holes contract in the length- and width- direction.

\[
\text{Temperature difference: } \Delta T = -60^\circ C
\]

\[
\text{Thermal expansion coefficient: } \alpha = 21.4 \frac{\mu m}{m K}
\]

#### Holders

The distances between the holders are as follows:

\[
\Delta L_h = L_{h0} \times \alpha \times \Delta T = 0.102 \times 21.4 \times (-60) = -130.968 \mu m \approx -0.131 mm
\]

\[
\Delta H_h = H_{h0} \times \alpha \times \Delta T = 0.062 \times 21.4 \times (-60) = -79.608 \mu m \approx -0.080 mm
\]

These differences are very small and the ICCS-module should not be damaged by the resulting force. To be assured of this, the holders could be covered with a cushioning material (Figure 80) like what was suggested in Figure 80.
Connectors

If the holes for the connectors are made very big they will differ about as much as the holders, a difference that can be overlooked.

7.9 Assembly

Both the assembly of the enclosure itself and how it might fit into the existing assembly will be described below.

7.9.1 Suggested procedure of assembly

1. The node should be assembled completely accept tor the cable cover before being brought to the ART’s frame. This includes isolators and bolts as far as possible.
2. The node is brought to the ART’s frame and mounted before the main cable harness.
3. Cables from the ECU are connected to the node.
4. All other components that are to be connected to the node are mounted and their cables are attached to a cable connector which is connected to the node.
5. After all components have been connected, the cable cover is installed.

7.9.2 Demounting

This concept allows the node to be demounted by someone working while sitting/lying down\(^3\) on the frame above it by having all nuts that needs loosening facing upwards (Figure 81). After loosening these nuts the node only needs to be pulled upwards leaving the bolts and dampers on the brackets. However, the cables need to be detached before the node is completely free.

---

\(^3\) This is hardly an ergonomic position to work in. Better options were considered, but since need for exchange of each node is – after all - very low, the design will have to facilitate exchanging as far as possible without compensating on other aspects, like ease of routing cables.
Demounting the isolators needs some more work, but can be done from above as well. The nuts have a lot of space around them so that tools can reach them without hassle.

### 7.9.3 Fool proofing

Does the design facilitate assembly? E.g. is it intuitive how the parts are assembled or is it close to impossible to assemble them incorrectly? The lid is symmetrical in two planes, meaning that it cannot be mounted incorrectly so long as it is not turned “up-side-down”, but the holders of the node, as well as the edge, clearly indicates the intended direction in this plane. Since it impossible to attach the cable connectors and cover in any other way than the intended one it is considered to be fool proof. Since the shape of the ICCS-module itself is symmetrical it is hard to design the holders to be fool proof. Placing it upside down is a mistake that will be realised quickly since the connectors will hit the “floor” of the enclosure, but the orientation otherwise could be tricky. Either the node itself would have to be modified so that it becomes clearer how it should be placed, or the solution could be to mould symbols into the “floor” indicating which port (they are labelled X1-X4) should be at which holder-“pin”.

Since it is not clearly indicated what is up and what is down on the enclosure the there is a risk that it could be mounted upside down. The correct orientation should be clearly indicated (e.g. “this side up” moulded into the upper side).

7.10 Routing of cables

This section will cover what components will be connected to the node and how their cables will be routed to get to it.

7.10.1 Components to connect

Whether the components should be connected to the node or not are listed in Table 19.

Table 19 – Components to connect and not to connect

<table>
<thead>
<tr>
<th>Index</th>
<th>Component</th>
<th>Comment</th>
<th>Included?</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>IMU</td>
<td>Will be connected, but was already on CAN</td>
<td>Yes/No</td>
</tr>
<tr>
<td>B</td>
<td>Temperature sensors</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>C</td>
<td>Tachometer</td>
<td>So long as the transfer speed between node and ECU - and possible waiting times - are within acceptable interval to not pose a safety risk concerning the ATC.</td>
<td>Yes</td>
</tr>
<tr>
<td>D</td>
<td>Load sensors</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>E</td>
<td>Back Lights</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>F</td>
<td>Turning signals</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>G</td>
<td>Reversing Camera</td>
<td></td>
<td>No</td>
</tr>
<tr>
<td>H</td>
<td>Angle sensor</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>I</td>
<td>Back-up alarm</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>J</td>
<td>License plate lamp</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>K</td>
<td>Reversing lamp</td>
<td></td>
<td>Yes</td>
</tr>
</tbody>
</table>
7.10.2 Suggested routing

As was suggested in 7.5, there might be benefits to having several connectors to make the cable harness more modular. This goes especially for the cables routed between the node and the wheel axles which are the hardest places to reach for the assembly personnel when connecting the cables. Therefore the cables going to the wheel axles are separate from the rest of the cable harness. The suggested routing can be seen in Figure 82 below.

![Figure 82 – Suggested routing of cables](image)

The strongest argument for the suggested position is that the current layout of the pipes through which the cables are routed today will not have to change, with the exception of a new manifold where the cables go between the main harness and the node. The number of cables going through the pipes is also subject to change of course.

7.10.3 Approximate length difference

The lengths have been approximated by looking at the CAD-model of an A60 (the largest model) to get the biggest differences possible. It was assumed that all components demanded one cable each. Also, components that are not going to be connected to the node were left out of the calculations.

The cables going from the ECU to the node and from the Node to the components were summed up to 40 meters.

In the case without the node however, the cable length were summed up to 132 meters.

To conclude: Even if these numbers could be based on unrealistic assumptions, the difference of 92 meters or the ratio of 3.3 is quite indicative of how much of a difference the node would make on the cable harness. Consider that with more cables to each component the gap would become even bigger (although the ratio would stay the same).
8 Results

The results achieved from the detail design will be briefly summarised below.

8.1 Enclosure

The resulting enclosure is illustrated in Figure 83. As can be seen there are several differences from the version presented in 7.1. The most notable changes can be seen in the width and the cable protection. Some new parts have been added as well, such as the pressure vent and the isolators.

Figure 83 – The final enclosure design
In Table 20 below, the measurements of the final design are displayed. They are, of course, still rather speculative since most are only set to be “reasonable” in the sense that they live up to the verified requirements (see 9.2) and aspire to live up to the ones that are not verified.

**Table 20 – The final measurements**

<table>
<thead>
<tr>
<th>Measured object</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Protective enclosure</strong></td>
<td></td>
</tr>
<tr>
<td>Mass</td>
<td>703 g</td>
</tr>
<tr>
<td>Wall thickness</td>
<td>5 mm</td>
</tr>
<tr>
<td>Length</td>
<td>150 mm</td>
</tr>
<tr>
<td>Height</td>
<td>105 mm (142 mm with cable cover plate)</td>
</tr>
<tr>
<td>Width</td>
<td>60 mm</td>
</tr>
<tr>
<td>Length between module-holders</td>
<td>102 mm (specified by ICCS-modules datasheet)</td>
</tr>
<tr>
<td>Height between module-holders</td>
<td>62 mm (specified by ICCS-modules datasheet)</td>
</tr>
<tr>
<td>Length of connector space</td>
<td>144 mm</td>
</tr>
<tr>
<td>Height of connector space</td>
<td>31 mm</td>
</tr>
<tr>
<td>Width of connector space</td>
<td>57 mm</td>
</tr>
<tr>
<td><strong>Cable cover</strong></td>
<td></td>
</tr>
<tr>
<td>Mass</td>
<td>112 g</td>
</tr>
<tr>
<td>Wall thickness</td>
<td>3 mm</td>
</tr>
<tr>
<td>Length</td>
<td>150 mm</td>
</tr>
<tr>
<td>Height</td>
<td>40 mm</td>
</tr>
<tr>
<td>Width</td>
<td>58 mm</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
</tr>
<tr>
<td>Mass</td>
<td>1099 g (module and lid included, isolators and brackets excluded)</td>
</tr>
</tbody>
</table>
8.2 Placement

The suggested placement and cable routing are displayed in Figure 84. The suggested routing rendered a shorter total cable length with ratio of 3.3 compared to the present routing (see 7.10 for more details).

Figure 84 – The suggested placement and cable routing
9 Conclusion

Here the results from the thesis will be summarised by answering each of the research questions. Also, the requirements will be reviewed.

9.1 Answers to the research questions

The three questions formulated as part of the goal in 1.3 are to be answered below.

Where should an intelligent node be installed and how should it be protected from damage?

The position that was found to be best suited for the node is shown in Figure 69. The enclosure designed to protect the ICCS-module will have it sealed entirely from the outside with the exception of a vent that is to relieve pressure and let moisture out of the enclosure. The greater part of the enclosure is made from an aluminium alloy with thick walls to properly protect it from mechanical damage. The ICCS-module is to be shielded from vibrations and shocks by being suspended in elastomeric isolators.

How should the new E&E-system be constructed so that the lengths of the cables between the components and the node are minimised?

By routing the cables from the position shown above through the existing main harness. This results in short lengths of cables while still staying within a variety of limits relating to durability of the frame, positions of existing components, leaving space to work for the assembly personnel, etc.

What components should/should not be connected to the node?

Most of the E&E-components in the load unit should be connected, the exceptions are those that are safety critical and not within the ICCS-module’s technical capacities. For details, see Table 19.
9.2 Verification of requirements

The requirements are revisited below, first each one is checked of as verified or not in Table 21. Comments for selected requirements/wishes will follow after the table.

*Table 21 – verification of requirements*

<table>
<thead>
<tr>
<th>Nr.</th>
<th>Description</th>
<th>Specification</th>
<th>Requirement /wish</th>
<th>Verified?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Needs to be dust- and waterproof.</td>
<td>IP66K and IP69K</td>
<td>Requirement</td>
<td>Yes</td>
</tr>
<tr>
<td>2</td>
<td>Should be able to protect the node from vibrations that the ART is expected to produce.</td>
<td>Chosen damping is specified to tolerate the VCE test-procedures for vibrations.</td>
<td>Requirement</td>
<td>No</td>
</tr>
<tr>
<td>3</td>
<td>Should be able to protect the node from shocks that the ART is expected to produce.</td>
<td>Chosen damping is specified to tolerate the VCE test-procedures for shocks.</td>
<td>Requirement</td>
<td>No</td>
</tr>
<tr>
<td>4</td>
<td>Tolerates expected humidity in all working conditions and geographical areas.</td>
<td>The enclosure is expected to leave the module functioning after being exposed to a humidity level of 10-100%</td>
<td>Requirement</td>
<td>No</td>
</tr>
<tr>
<td>5</td>
<td>Should protect the node from mechanical damage coming from outside the shell. The node should not be damaged by forces from the enclosure budging, it should still be fully functional and the ingress protection is not to be compromised.</td>
<td>Tolerates Point load ≥ X kN Surface load ≥ X kN/cm² Shear load ≥ X kN Projectile hit of 0.5kg object falling from 5m height</td>
<td>Requirement</td>
<td>No</td>
</tr>
<tr>
<td>6</td>
<td>Cooling should be sufficient to keep the node within operating temperatures.</td>
<td>Average temperature inside enclosure should stay between -40 °C and 85 °C. Testing will only be done for the maximum temperature.</td>
<td>Requirement</td>
<td>Yes</td>
</tr>
<tr>
<td>7</td>
<td>The nodes ingress protection should not be compromised by pressure build or drop from temperature or altitude variations.</td>
<td>The enclosure has the capacity of evening out expected pressure build or drop.</td>
<td>Requirement</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Enclosing and Mounting an Electronic Component on Articulated Haulers

<table>
<thead>
<tr>
<th>Placement of node</th>
<th>Requirement</th>
<th>Wish</th>
<th>Yes</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 Places where standard components and attachments are usually mounted should be avoided.</td>
<td>See 3.1.3 and 3.1.4</td>
<td>Requirement</td>
<td>Yes</td>
</tr>
<tr>
<td>9 Screw holes cannot be placed in frame walls.</td>
<td>See 3.1.6</td>
<td>Requirement</td>
<td>Yes</td>
</tr>
<tr>
<td>10 Custom tools should not be needed when mounting the node.</td>
<td>N/A</td>
<td>Wish</td>
<td>Yes</td>
</tr>
<tr>
<td>11 The node should be mounted and demounted with as few tools as possible</td>
<td>N/A</td>
<td>Wish</td>
<td>No</td>
</tr>
<tr>
<td>12 The cable length between each load sensor and the intelligent node should be minimised.</td>
<td>N/A</td>
<td>Requirement</td>
<td>Yes</td>
</tr>
<tr>
<td>13 The total cable length between components and the intelligent node should be minimised.</td>
<td>N/A</td>
<td>Wish</td>
<td>Yes</td>
</tr>
<tr>
<td>14 The cables between each load sensor and the intelligent node should be equal in length.</td>
<td>N/A</td>
<td>Wish</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Comments to some of the requirements can be found below.

**Nr.2&3:** See 7.6.3.

**Nr.4:** Not processed.

**Nr.5:** As no calculations on a similar product were made to get something to benchmark it against, this requirement could not be defined or confirmed. However, it would be surprising if the specified enclosure would fail in this aspect.

**Nr.6:** See 7.8.1.

**Nr.7:** See 7.4.

**Nr.11:** Two tools are more than most of the existing components on the ART need.

**Nr.12:** The cable harness is in between the two sensors with almost no detours in the routing at all, meaning that the total length between sensors and node could not have been much shorter. As for being equidistant from the node, see Nr.14 below.

**Nr.13:** Even though, it has not been mathematically confirmed as a minimum, the suggested solution should be close to a minimum so long as the present harness is kept and the length only depends on the nodes position.

**Nr. 14:** In the suggested routing, cable length between the node and the front load sensor were measured to be about 3.30 meters while the distance to the sensor in the back was about 2.8 meters. That is a difference of 0.5 meters. This can be compared to the present difference in length between each cell and the ECU which is the total distance between the two load sensors, i.e. 3.3+2.8 = 6.1 meters. They may not be completely equal, but they are within an acceptable margin.
9.3 Final statement

In the end the end, the following can be said about the result of this thesis:

- The thesis has arrived in a proposition for the enclosure, a placement and a cable routing.
- All requirements were not verified and the vibration requirement was not fulfilled. This means that further development of the damping will be needed, as well as testing to verify the remaining requirements. However, the suggested design should be able to fulfil all requirements with little or no modifications.
- A reasonable position on the ART that renders good results in respect to assembly has been found. It also fulfils all known constraints.
- The suggested cable routing would decrease the total cable length at a ratio of around 3.3 compared to the present length which is a considerable improvement.
10 Discussion

Things that could have gone better, would have been done differently if done again, personal opinions or comments that did not have a given space in the rest of the thesis are going to be brought up below.

10.1 Requirements

In retrospect, it seems odd that a requirement for the voltage drop were not included in the specifications, seeing how it is a big part of the goal of this essay to lower it. The author is quite certain that this goal has been achieved, but without a set requirement it is hard to verify or even make a valid argument that this is actually the case.

10.2 Method

The method was not always followed as intended. This was regrettable since it led to a less organised work process which led to a lot of wasted effort and a less focused result. A more detailed planning with rigorous check points to see that the plans were followed would have been preferred.

10.3 Concept generation

The level of detail on the methods in phase 1 varied too much. An example is gaskets vs. isolators where gaskets got a lot more attention. It would have been preferable to have gaskets as one part concept just like the isolators since it was very hard to judge the difference a certain type of gasket would make in an otherwise low-detail-concept.

Welded brackets should have been included among the placement concepts. Getting comments on this from the engineers and assembly personnel during the evaluation phase would have been useful.

Doing some calculations earlier than the detail design could have abolished some uncertainties that were present during this phase. The heat calculations are an example of calculations that could have been done earlier to realise that the cooling did not require as much attention as it was given. The same goes for the vibrations and shocks.

10.4 Concept evaluation and selection

Discussing with both assembly personnel and engineers were very useful for getting qualitative and diverse information on the haulers. These interviews are a good example of something that would have been made differently if done again. Now that more knowledge has been unearthed, it would be easier know what to ask.
The concepts could have been described better during the engineer’s review. It was hard
to grasp what was intended with some concepts, or parts of them, e.g. how the potting
compound interacted with the node and enclosure. It was probably hard to grade the
concepts since the detail level of the concepts did not justify putting the parts together.
It is possible that this led to the more novel concepts getting lower scores than they
actually deserved. Another alternative would have been to let the respondents grade
selected part concepts instead, since it would have been easier to see possibilities and
limitations of lone part-concepts than complete low-detail-concepts. Another point to
make on the engineer’s review is that both of the variants of the moulded enclosure
should have been described in the query. In the end however, the reviews gave a lot of
useful information and the result would not have been as good if the author would have
performed the evaluation himself.

Another concern from the engineer’s review is the selection criteria that were removed.
This was done since they seemed more relevant to the assembly personnel, but it might
have been better to include them in retrospect. It is also regrettable that a selection
criteria concerning damping were not included in the placement concepts, but most
recipients paid attention to this anyway and mentioned it in the comments.

10.5 Detail design

Since changes of many details had big effects on other ones, phase 3 got somewhat
disorganised in parts. However dividing it up into “function-areas” did come with some
advantages as well; with each change something new was realised which made the final
design better, e.g. considering a wider enclosure led to the realisation of how to make
several small, but – possibly – crucial modifications for the sake of improving the
damping.

With the increased width, the module’s holders became longer. This is problematic
since the node’s measurements limits them from increasing in diameter and therefore
becomes less stable with increasing length.

In retrospect, to put the isolators in the inside of the enclosure might have been a better
choice in the end, since the not much space – if any – were saved by having them on the
outside. Having them on the inside would have opened up for a sturdier mount of the
node to the ART. The requirement on the isolators to tolerate harsh environments would
have been removed as well, meaning that greater focus could have been put on finding
an isolator with a low natural frequency and other parameters. In this case, the module’s
holders would not have been necessary, they would have had to be replaced by
something to mount the isolators on, surely, but one can imagine that it would have
been better for the node’s stability.

10.6 Results

Since the proposed concept has not yet been subjected to prototyping and testing it is
highly probable that flaws would be discovered if it would come to be further
developed. This would require the concept to once again go through some detail design
and be altered in one aspect or another before it can pass the technical requirements
defined by VCE. An iterative process that is common to most products.
If the ICCS-module would change from being exchanged or updated, the enclosure would have to change as well. This might not have great implications on the manufacturing of the enclosure since the sand-casting moulds are made new for each manufactured unit. However, it will most likely have effects on other areas where it might be more problematic. In the best case, only the module’s holders will have to be repositioned, but if the modules dimensions are much smaller or larger than before, the enclosure might have to be changed in size. This would mean that new isolators have to be considered. A solution less dependent on the size of the ICCS-module (e.g. adjustable holders and generous margins inside the enclosure) would have been preferable. The enclosure still needs a lot of work if it is to live up to all of VCE’s technical requirements, but it should be well on its way there. The design contains many ideas that will hopefully be of help to the employees and customers of VCE.
11 Future studies

*Below are some possible directions to take if going further in this project and suggestions on other topics that could be interesting to look into either for a future student or an employee at VCE.*

The node taken forth during this project needs more development on many areas. One is further verification against the technical requirements at VCE, e.g. resistance against cold temperatures, sudden temperature fluctuations, chemical exposure, mist, etc. Others are a better look at the E&E-hardware - like connectors - as well as the software.

If the suggested solution would be used, it might be possible – with the current level of detail - to optimise the design by translating the problem into an optimisation model and solving it by using algorithms.

The ART is sometimes sold without a load unit to which custom “back-ends” can be connected. A lot of the E&E-equipment still comes with it however, meaning that it could be good to plan how to prepare the node for this.

The present load measuring cells has an analogue output-signal which has been converted from a digital signal in the cell. The analogue signal will later be converted into digital form again when going from the CAN-bus. A more logical procedure would be for the cell to send the information digitally to the CAN-bus to begin with. However, this would require a completely new kind of load cell to be installed in the ART’s since the present model does not provide this possibility. On the bright side; apart from having to acquire new load measuring cells, the change could be quite painless. A digital cell might also bring some advantages with it when it comes to calibrating the device since several cells could be calibrated at once. It could also be done from a distance since the communication needed can be sent through the CAN-network. This would seem very practical compared to the present situation where every cell has to be calibrated by plugging a computer into a separate port on the cell itself.

Modularisation of E&E-cables is a suggestion that turned up when discussing with the assembly during this project. It seems that both time and effort could be saved in the assembly if the main cable harness were split up. Maybe so that small bits of cable could be routed from each individual component to a gathering point in the main harness. This has been slightly touched upon in this thesis, since the node could be considered a natural gathering point, but further investigations on whether this can be solved practically or not seems necessary.

Improving the protection of cables inside the harness’ plastic tubes could seem to be an object of interest at VCE which could be part of a future project.
References

Literature


Enclosing and Mounting an Electronic Component on Articulated Haulers


Figures


Enclosing and Mounting an Electronic Component on Articulated Haulers

Appendix 1 – ICCS-module’s datasheet

ICCS – Intelligent Control and Command Systems

Applications
- Monitoring of fans and switching of relays
- Control unit for central electrical distribution
- Interface to CAN bus
- CAN to CAN Gateway
- Input/output interface
- Graphically programmable control unit for mobile applications

Technical data

<table>
<thead>
<tr>
<th>General information</th>
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<tbody>
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<td>Connector</td>
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<tr>
<td>Storage temperature</td>
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<td>ESP/WIP</td>
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CAN Bus

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<td>iso. CAN 2-B</td>
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<td>iso. CAN 2-B</td>
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<td>Bus rate</td>
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Inputs/outputs overview

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<tr>
<td>Analogue Inputs</td>
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</tr>
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<td>Digital Inputs</td>
<td>0-11 V DC</td>
</tr>
<tr>
<td>Digital Outputs</td>
<td>Switch On/Off level, current sense, high side output up to 2 A</td>
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<tr>
<td>Inputs/outputs details</td>
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</table>

Analogue inputs

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<tr>
<td>Input range</td>
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<td>Resolution</td>
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<td>Input resistance</td>
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<tr>
<td>Pull-up resistance</td>
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Digital inputs

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<thead>
<tr>
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<tbody>
<tr>
<td>Input voltage</td>
<td>0 V DC to supply</td>
</tr>
<tr>
<td>Switch-on level</td>
<td>0 V (15 V version 15 V (24 V))</td>
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<tr>
<td>Switch-off level</td>
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Digital outputs

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<td>Load current</td>
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<td>I/O outputs</td>
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<tr>
<td>Input resistance</td>
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<tr>
<td>Input frequency</td>
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</table>

www.wuerth.de
ICCS
64P CAN Controller

Hardware Map
## Enclosing and Mounting an Electronic Component on Articulated Haulers

### ICCS 64P CAN Controller

#### Pin assignment

<table>
<thead>
<tr>
<th>X3 Connector</th>
<th>Pin</th>
<th>Description</th>
<th>Function</th>
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<tbody>
<tr>
<td>1</td>
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<td></td>
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<tr>
<td>2</td>
<td>AIN_O_H</td>
<td>Analogue input 0-10 V or 0-20 mA</td>
<td></td>
</tr>
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<td>AIN_R</td>
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<tr>
<td>5</td>
<td>AIN_R</td>
<td>Analogue input 0-10 V or 0-20 mA</td>
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<tr>
<td>6</td>
<td>DININ_R</td>
<td>Digital input with I/O</td>
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</tr>
<tr>
<td>7</td>
<td>DININ_L</td>
<td>Digital input with I/O</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>DININ</td>
<td>Digital input</td>
<td></td>
</tr>
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<td>9</td>
<td>AIN_O_L</td>
<td>Analogue input 0-10 V or 0-20 mA</td>
<td></td>
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<tr>
<td>10</td>
<td>AIN_O_L</td>
<td>Analogue input 0-10 V or 0-20 mA</td>
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<td>11</td>
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<td>Analogue input 0-10 V or 0-20 mA</td>
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<tr>
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#### X4 Connector

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<td>Digital input</td>
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<tr>
<td>6</td>
<td>DININ</td>
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<tr>
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</tr>
<tr>
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<td>DININ_L</td>
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<td>DININ_L</td>
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<tr>
<td>1</td>
<td>B + 2</td>
<td>Power Supply for outputs 0-3</td>
</tr>
<tr>
<td>2</td>
<td>+5V Out</td>
<td>+5 V 250 mA voltage reference</td>
</tr>
<tr>
<td>3</td>
<td>+10V Out</td>
<td>+10 V 350 mA voltage reference</td>
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<tr>
<td>4</td>
<td>CAN_L</td>
<td>CAN Bus 0 Low</td>
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<tr>
<td>5</td>
<td>CAN_H</td>
<td>CAN Bus 0 High</td>
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<tr>
<td>6</td>
<td>CAN_L</td>
<td>CAN Bus 1 Low</td>
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<tr>
<td>7</td>
<td>CAN_H</td>
<td>CAN Bus 1 High</td>
</tr>
<tr>
<td>8</td>
<td>B + 2</td>
<td>Power Supply for outputs 0-3</td>
</tr>
<tr>
<td>9</td>
<td>DIGOUT_H</td>
<td>Digital output max 2 A</td>
</tr>
<tr>
<td>10</td>
<td>DIGOUT_H</td>
<td>Digital output max 2 A</td>
</tr>
<tr>
<td>11</td>
<td>DIGOUT_H</td>
<td>Digital output max 2 A</td>
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<tr>
<td>12</td>
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<td>Digital output max 2 A</td>
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<tr>
<td>13</td>
<td>DIGOUT_H</td>
<td>Digital output max 2 A</td>
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<tr>
<td>14</td>
<td>DIGOUT_H</td>
<td>Digital output max 2 A</td>
</tr>
<tr>
<td>15</td>
<td>DIGOUT_H</td>
<td>Digital output max 2 A</td>
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#### X1 Connector

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<td>0 + 3</td>
<td>Power Supply for outputs 0-15</td>
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<td>VIN</td>
<td>Ground</td>
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<td>AIN_O_L</td>
<td>Analogue input 0-10 V</td>
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<td>AIN_O_L</td>
<td>Analogue input 0-10 V</td>
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<td>Analogue input 0-10 V</td>
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<td>8</td>
<td>AIN_O_L</td>
<td>Analogue input 0-10 V</td>
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<tr>
<td>9</td>
<td>DIGOUT_H</td>
<td>Digital output max 2 A</td>
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<tr>
<td>10</td>
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<tr>
<td>11</td>
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</tr>
<tr>
<td>16</td>
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</tr>
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* For 10 V reference only available when changing greater than 10 V
ICCS
64P CAN Controller

Dimensions

Order information

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<th>Mating connector</th>
<th>Part number</th>
<th>WE IGS</th>
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<td>ICS-07104</td>
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<td>649 016 113 322</td>
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</tr>
<tr>
<td>D Wing contact, WE-MPC4, AWG 16</td>
<td>649 016 137 22</td>
<td></td>
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<tr>
<td>D Wing contact, WE-MPC4, AWG 24-18</td>
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<tr>
<td>D Wing contact, WE-MPC4, AWG 26/22</td>
<td>649 003 137 22</td>
<td></td>
</tr>
</tbody>
</table>

For more information visit us at www.we-online.com or call +49 7940 1910-0.

Würth Elektronik ICS GmbH & Co. KG
Intelligent Connecting Systems
Gemeinde Waldshut
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Tel. +49 7940 6910-0
Fax +49 7940 6910-189
ics@we-online.de
www.we-online.com
Enkät: koncept angående installation av en intelligent nod


Bär gärna med dig att detta endast är halvfärdiga koncept. Detaljer såsom skruvhål, dimensioner, vilken sida kabelportarna sitter på, etc. kommer troligtvis att ändras. Det viktiga i den här enkären är din åsikt angående de stora dragen, t.ex. din tro på att den stängnings-funktion som kan ses i koncept 1:1 skulle vara möjlig att tätta tillräckligt väl för att uppnå IP69K. Att listen kanske är för smal eller sitter skevt är inte viktigt i detta skede. Jag tar sålunda gärna emot förslag eller kritik i kommentarsfälten om du kommer på något, t.ex. hur jag kan ändra befintliga koncept för att göra dem bättre, oavsett om det gäller detaljer eller större grejer.
1 Inkapsling
Inkapslings-koncepten beskrivs i det här avsnittet. Kriterierna tolkas enligt följudringsarna nedan.

Tätning – Hur enkel designen är att täta (den ska uppnå IP66K och IP69K).

Dämpning – Lämpligheten för den vibrations- och stöt-dämpning som föreslås i kombination med resten av konceptet.

Hållfasthet – Hur rimlig om den grundläggande designen på skalet är om det ska hålla de förväntade påfrågningarna.

Montering – Hur väl skalets design underlättar montering av noden.

Kostnad - Hur kostnads-efektivitet konceptet i fråga bör vara jämfört med de andra (avseende besparinger och extra kostnader)
**Koncept 1:1**


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<td>Dämpning</td>
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<td>Hållfasthet</td>
<td>-</td>
</tr>
<tr>
<td>Montering</td>
<td>-</td>
</tr>
<tr>
<td>Kostnad</td>
<td>-</td>
</tr>
</tbody>
</table>

Här nedan kan eventuella kommentarer lämnas
**Koncept 1:2**

Skålet är i stort som koncept 1:1 ovan. Låset är dock utbytt mot ett med samma kolv som finns i många dörrar (se bild). Dämpningen har bytts ut mot dynor som monteras vid nodens fästpunkter, som på bilden nedan.

<table>
<thead>
<tr>
<th>Kriterie</th>
<th>Betyg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tätning</td>
<td>-</td>
</tr>
<tr>
<td>Dämpning</td>
<td>-</td>
</tr>
<tr>
<td>Hållfasthet</td>
<td>-</td>
</tr>
<tr>
<td>Montering</td>
<td>-</td>
</tr>
<tr>
<td>Kostnad</td>
<td>-</td>
</tr>
</tbody>
</table>

Här nedan kan eventuella kommentarer lämnas.
Koncept 1:3

<table>
<thead>
<tr>
<th>Kriterie</th>
<th>Betyg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tätning</td>
<td>-</td>
</tr>
<tr>
<td>Dämpning</td>
<td>-</td>
</tr>
<tr>
<td>Hållfasthet</td>
<td>-</td>
</tr>
<tr>
<td>Montering</td>
<td>-</td>
</tr>
<tr>
<td>Kostnad</td>
<td>-</td>
</tr>
</tbody>
</table>

Här nedan kan eventuella kommentarer lämnas
Koncept 1:4
Själva modulen sitter på en bas som omsluts av en svänglucka. Luckan låses med ett “haklös” (se bild för exempel). Tätning behövs längs med luckans kanter och i kabelportarna. Att montera själva noden med skruvar i lådan kommer undvikas, den ska kunna tas ut och bytas enkelt. Vibrations/stöt-
dämpning görs med hjälp av samma sorts dynor som i koncept 1:2 ovan.

<table>
<thead>
<tr>
<th>Kriterie</th>
<th>Betyg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tätning</td>
<td>-</td>
</tr>
<tr>
<td>Dämpning</td>
<td>-</td>
</tr>
<tr>
<td>Hållfasthet</td>
<td>-</td>
</tr>
<tr>
<td>Montering</td>
<td>-</td>
</tr>
<tr>
<td>Kostnad</td>
<td>-</td>
</tr>
</tbody>
</table>

Här nedan kan eventuella kommentarer lämnas

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2 Placering

Här presenteras förslag på placering av noden. Kriterierna tolkas enligt nedan.

Stadighet – Hur pass enkelt det är att montera noden så att den sitter tillräckligt stadigt.

Projekttilskydd – Hur väl skyddas den från fallande objekt, eller object som skjuts upp underifrån

Kabeldragning – Hur väl anpassad platsen och vinkeln är för att dra kablar.
Koncept 2:1
Liggande horisontellt längst fram till vänster i rutten, dvs. i samma hörn som ”kabeltunneln”. Komponenten ligger monterad på en platta som i sin tur fästes i ramens horisontella yta. Nedan illustreras placeringen med de två öppningsbara inkapslingskoncepten.

<table>
<thead>
<tr>
<th>Kriterie</th>
<th>Betyg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stadighet</td>
<td>-</td>
</tr>
<tr>
<td>Projektilliskydd</td>
<td>-</td>
</tr>
<tr>
<td>Kabeldragning</td>
<td>-</td>
</tr>
</tbody>
</table>

Här nedan kan eventuella kommentarer lämnas
Koncept 2:2
Placering på samma ställe som i koncept 2:1, men i vertikalt läge. I detta fall fästs noden i ett vinkeljärn som i sin tur endast fästs i ramens horisontella yta (hål får inte göras i de vertikala ytorna).

<table>
<thead>
<tr>
<th>Kriterie</th>
<th>Betyg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stadighet</td>
<td>-</td>
</tr>
<tr>
<td>Projektilskydd</td>
<td>-</td>
</tr>
<tr>
<td>Kabeldragning</td>
<td>-</td>
</tr>
</tbody>
</table>

Här nedan kan eventuella kommentarer lämnas
Koncept 2:3
Noden placeras på ett vinkeljärn som monteras på ramens vänstra insida (se bild).

<table>
<thead>
<tr>
<th>Kriterie</th>
<th>Betyg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stadighet</td>
<td>-</td>
</tr>
<tr>
<td>Projektiskydd</td>
<td>-</td>
</tr>
<tr>
<td>Kabeldragning</td>
<td>-</td>
</tr>
</tbody>
</table>

Här nedan kan eventuella kommentarer lämnas
Koncept 2:4
Noden monteras på en modifierad version av back-larmets skydd (se bild).

<table>
<thead>
<tr>
<th>Kriterie</th>
<th>Betyg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stadighet</td>
<td>-</td>
</tr>
<tr>
<td>Projekttilskydd</td>
<td>-</td>
</tr>
<tr>
<td>Kabeldragning</td>
<td>-</td>
</tr>
</tbody>
</table>

Här nedan kan eventuella kommentarer lämnas
## Appendix 3 - Morphological matrix

<table>
<thead>
<tr>
<th>Functions</th>
<th>Means</th>
<th>Complexity modules</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell concept</td>
<td>Jacobi, Laplace</td>
<td></td>
</tr>
<tr>
<td>Joinkaering of shell, forces</td>
<td>Stiffness, buckling</td>
<td></td>
</tr>
<tr>
<td>Scaling</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Cable parts</td>
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<td></td>
</tr>
<tr>
<td>Damping</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Cooling</td>
<td>None</td>
<td></td>
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<tr>
<td>Pressure, moisture ventilation</td>
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<tr>
<td>Hood</td>
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<tr>
<td>Split links</td>
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<tr>
<td>Stiffened girders</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Pin and play</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Thill up</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>External fan</td>
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<td></td>
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<tr>
<td>Pressure, moisture ventilation</td>
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<td></td>
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<tr>
<td>Drawer</td>
<td>Separate screws</td>
<td></td>
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<tr>
<td>Knob</td>
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<td></td>
</tr>
<tr>
<td>Glue</td>
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</tr>
<tr>
<td>Bum-off gaskets</td>
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<td></td>
</tr>
<tr>
<td>Clamp</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Initials</td>
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</tr>
<tr>
<td>Heat tanks</td>
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<tr>
<td>Cabinet</td>
<td>None</td>
<td></td>
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<tr>
<td>Slot</td>
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<tr>
<td>Food box</td>
<td>None</td>
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</tr>
<tr>
<td>Pulling components</td>
<td>None</td>
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</tr>
<tr>
<td>Central</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Hatch</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Lever latch, lock</td>
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<td></td>
</tr>
<tr>
<td>Hook, lock</td>
<td>None</td>
<td></td>
</tr>
</tbody>
</table>

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Appendix 4 – Pressure vent’s data sheet

Automotive Vents
FOR SNAP-FIT INSTALLATION

Increase durability and performance of automotive electronics

VENTING FOR PROTECTION
The controls, motors and sensors of today's sophisticated automotive electronics require reliable sealed enclosures to protect against harsh road conditions. GORE® Automotive Vents improve reliability and extend component life. These durable vents reduce pressure differentials with continuous airflow in and out of the enclosure, while blocking contaminants such as water, automotive fluids, salts, dirt and mud. As a qualified automotive partner, Gore delivers advanced venting technologies in a variety of forms to fit any application—welded vents, adhesive vents and snap-fit vents.

VENTING SOLUTIONS FOR ELECTRONIC CONTROL UNITS
Snap-Fit Vents set the standard for the protection required by control units, motors and sensors. These mechanically rugged vents are easy to integrate without requiring additional design consideration. Gore's engineering team works closely with its customers to identify the optimal venting solution for each application:

- The standard series is suitable for components exposed to typical automotive fluids and continuous temperatures up to 125 °C, with short-term spikes up to 160 °C.
- The high-temperature series maintains its long-lasting resistance to chemicals and mineral acids; they do not break down even after extended exposure to temperatures up to 150 °C.
- Engineered specifically for very large components (e.g., electric motors or batteries for hybrids), the high airflow series equalizes pressure with a typical airflow as much as five times greater than the standard series.
- Approximately 30 percent smaller than other GORE® Snap-Fit Vents, the compact series provides a higher level of protection for extremely small electronic components, where space is at a premium.

REALIZE THE BENEFITS OF GORE® AUTOMOTIVE VENTS FOR SNAP-FIT INSTALLATION
- Worry-free venting solution with total quality control and integrated design that protects the membrane.
- Easy integration with no additional parts or complicated housing designs in either plastic or metal enclosures.
- Easy installation, whether for a small series in manual or semi-automated installation or for automated installation of high-volume applications.
- Durable protection against liquids, dust, dirt, salts and corrosive automotive fluids.
# Appendix 4 – Pressure Vent’s Data Sheet

## Product Information

### PolyVent Standard Series
- **Product Number:** AV5 16
- **Product Number:** AV500 154

### PolyVent High-Temperature Series
- **Product Number:** AV5 67
- **Product Number:** AV500 667

### PolyVent High-Antiseptic Series
- **Product Number:** AV5 70
- **Product Number:** AV500 705

## Product Performance
- **Maximum pressure at standard ambient temperature and pressure:** 3.6 kPa/30 sec
- **Maximum air flow at standard ambient temperature and pressure:** 4.1 l/min at 7 kPa
- **Typical output at standard ambient temperature and pressure:** 4.1 l/min at 7 kPa
- **Ingress Protection (IP):**
  - PolyVent: IP66
  - PolyVent High-Temperature: IP66
  - PolyVent High-Antiseptic: IP66

## Operating Conditions
- **Operating temperature:**
  - PolyVent: -40°C to +125°C
  - PolyVent High-Temperature: -40°C to +135°C
  - PolyVent High-Antiseptic: -40°C to +125°C
- **Minimum characteristic:**
  - PolyVent: Hydrophilic and antiseptic
  - PolyVent High-Temperature: Hydrophilic and antiseptic
  - PolyVent High-Antiseptic: Hydrophilic and antiseptic
- **Material:**
  - PolyVent: PBT GF30% Nylon
  - PolyVent High-Temperature: PBT GF30% Nylon
  - PolyVent High-Antiseptic: EPDM
- **Color:**
  - PolyVent: Black
  - PolyVent High-Temperature: Red
  - PolyVent High-Antiseptic: Black
- **Laser marking:**
  - PolyVent: Yes
  - PolyVent High-Temperature: Yes
  - PolyVent High-Antiseptic: Yes

## Design and Dimensions

### Recommended Installation

*Please consult your vendor representative for more detailed installation drawings.*
Enclosing and Mounting an Electronic Component on Articulated Haulers

Environmental Performance

Environmental Vortex fans have been extensively tested according to the following performance standards. Please contact your GE representative for more detailed information.

Temperature Resistance Test

Verify durability under low and high temperature conditions

Method:
• ISO 5607-6
Test conditions:
• Test procedure: cycle of temperature between Tmin and Tmax within 30 seconds
• 30 minutes conditioning at each temperature
• Minimum 300 cycles

Thermal Shock Resistance Test

Verify durability under changing temperature conditions

Method:
• ISO 5607-6
Test conditions:
• Cycle of temperature between Tmin and Tmax within 30 seconds
• 30 minutes conditioning at each temperature
• Minimum 300 cycles

Climatic Resistance Test

Verify durability in hot humid environments

Method:
• ISO 5607-6
Test conditions:
• 85°C temperature
• 85% relative humidity
• 1,000 hours

Vibration and Mechanical Shock Resistance Test

Verify performance after exposure to mechanical shocks at various temperatures

Method:
• ISO 5607-6
Performance depends on structural and temperature profiles, pulse shapes and duration in unlike modes of mechanical vibrations.orgen factor measures the furnace severity levels

Liquid Contamination Test

Verify protection against chemical attacks

Method:
• ISO 5607-6
Performance depends on application method (a, b, c, d, e, f).常用的化学物质包括：酸，碱，盐，溶剂，油，以及特定的化学物质混合物。
Appendix 5 – Isolator datasheet

BTR® BROAD TEMPERATURE RANGE MOUNTS

HT SERIES

PROVIDE EXCELLENT, ALL-ATTITUDE CONTROL OF VIBRATION AND RESISTANCE TO ENVIRONMENTAL EXTREMES

BTR® Broad Temperature Range Elastomer Mounts are vibration control isolators designed for protection of sensitive equipment exposed to severe dynamic conditions. Developed especially for critical applications and high performance aircraft, missile, spacecraft and vehicular environments, they are compact and highly efficient. The HT Series Mounts are suitable for all-altitude mounting systems that require natural frequencies above 20 Hz in the ambient temperature from -65°F to +300°F (-54°C to +149°C).

The excellent internal damping capability of BTR elastomer limits amplification at resonance to 3.5 or less under typical application conditions.

HT Mounts are available in four basic series: HT0, HT1, HT2 and HTC. Inverted designs with identical performance are available in the same corresponding series UT1 and UT2.

Their compactness permits designers to utilize internal suspension arrangements, eliminating the need for sway space outside the case.

BTR Mounts incorporate a reliable elastomer-to-metal bond in a mechanical saturated assembly. Repeat checks at 15g, 11ms, half-sine pulse inputs reveal no reduction in isolation efficiency. The mount withstands shock impulses of 30g, 11ms, half-sine pulse without failure.

Features:
- Resonant frequency and transmissibility are virtually constant from -65°F to +300°F (-54°C to +149°C)
- Amplification at resonance is 3.5 or less under typical conditions
- Mechanically saturated assembly incorporates a reliable elastomer-to-metal bond
- Inputs at resonance can be as high as 0.06 inch D.A.
- Efficiently isolates disturbing forces in all directions

![Diagram of typical installation](image)

FIGURE 1 – TYPICAL INSTALLATION

Toll-Free: +1 877 ASK LORD (275 5673) | E-mail: customer.support@lord.com
Enclosing and Mounting an Electronic Component on Articulated Haulers

**BTR® BROAD TEMPERATURE RANGE MOUNTS**

**HT0 SERIES**

- **Load capacity:** 1 to 7 lb (0.45 to 3.2 kg) per mount
- **Finish:**
  - Outer member – chrome treated per MIL-DTL-5541, Class 1A, outside grey lacquer point (Part T-743-32)
  - Inner member – chrome treated per MIL-DTL-5541, Class 1A
  - Washer – stainless steel anodized and sprayed grey
- **Materials:**
  - Outer member – 300 aluminum or 6061-T6 aluminum
  - Inner member – 2024-T351 aluminum
  - Washer – 2024-T6 or 2024-T4 aluminum
  - Elastomer – LORD GTFF300

---

**TABLE 1 – PERFORMANCE CHARACTERISTICS**

<table>
<thead>
<tr>
<th>Part Numbers</th>
<th>Load State (kgf)</th>
<th>Moment of Inertia (kgf cm²)</th>
<th>Dynamic Coefficient</th>
<th>Dynamic</th>
<th>Max. Radial Force (kgf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HT0-1</td>
<td>1.5</td>
<td>52</td>
<td>1.3</td>
<td>2.9</td>
<td>26</td>
</tr>
<tr>
<td>HT0-2</td>
<td>2.0</td>
<td>52</td>
<td>1.1</td>
<td>2.9</td>
<td>26</td>
</tr>
<tr>
<td>HT0-3</td>
<td>1.5</td>
<td>52</td>
<td>1.1</td>
<td>2.9</td>
<td>26</td>
</tr>
<tr>
<td>HT0-4</td>
<td>2.0</td>
<td>52</td>
<td>1.1</td>
<td>2.9</td>
<td>26</td>
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<tr>
<td>HT0-5</td>
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<td>52</td>
<td>1.1</td>
<td>2.9</td>
<td>26</td>
</tr>
</tbody>
</table>

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**FIGURE 1 – HT0 SERIES PART DIMENSIONS**

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**FIGURE 2 – TRANSMISSIBILITY VS. FREQUENCY**

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**FIGURE 3 – LOAD VS. DEFLECTION**

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