Concept development of communications-enabled motorcycle helmet

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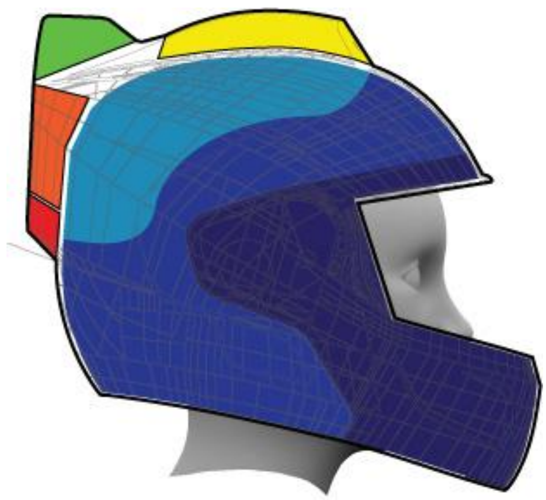

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2009-02-27	Priidu Pukk	Priidu Pukk
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Abstract

An innovative motorcycle helmet design concept was developed in order to fit an inter-helmet communications system to be used by the West Midlands police in the United Kingdom. The concept was to include: video camera, GPS and microphone system among other components specified by the target user. Three concepts were developed and evaluation methods were used to choose among them. The final concept was then further developed by conducting material and dimension analysis and choosing components and designing parts. Safety regulations, manufacturing methods and usability aspects were taking into consideration during the process. The developments led to an innovative helmet shape to store the components of communication system on the top and back of the helmet. The helmet shell should be of fiber reinforced plastic and for the protective padding EPS foam with different densities for different part of the padding is suggested. On top of the helmet a video camera would be placed in order to collect footage of suspect situations the policeman might encounter. Camera type, mounting of the camera and camera module design were investigated. Guidelines for making a prototype to be used when testing the helmet communications system were stated. Because of costs the concept and the prototype have essential differences.

KTH Industriell teknik och management

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Konceptutveckling av motorcykelhjälm med inbyggt kommunikationssystem

Sofia Henriksson

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Sammanfattning

Ett innovativt koncept av en motorcykel hjälm utvecklades i syfte att införa ett kommunikationssystem i hjälmen. Hjälmen var tänkt att användas av motorcykelburna poliser i distriktet West Midlands i Stor Britannien. Konceptet innebar att bland annat en videokamera, GPS och ett mikrofon- och hörlurssystem skulle integreras i hjälmen tillsammans med andra komponenter som specificerades av användargruppen. Tre konceptutvecklades och evaluerades. Det slutgiltigt valda konceptet bearbetades genom materialanalys och dimensionering. Specifika komponenter valdes utför att uppfylla användarkraven och hjälmens olika delar utvecklades för att rymma dessa. Säkerhets bestämmelser, tillverkningsmetoder och användaraspekter tog i beaktande under utvecklingsarbetet. Konceptutveckling resulterade i en innovativ motorcykelhjälm, utformad för att rymma kommunikationssystemet i toppen och på baksidan av hjälmen. Det föreslogs att hjälmens yttre skal ska tillverkas av fiberförstärkt plast och den inre, skyddande stoppningen ska bestå av EPS-skum med varierande densitet för olika områden i hjälmen. Videokameran placeras ovan på hjälmen och kan samla in bilder om polismannen så önskar. Kamerans typ, montering undersöktes och en modul för att integrera kameran i hjälmen konstruerades. Dessutom togs riktlinjer för tillverkning av en prototyp av hjälmen fram, på grund av kostnader kom den föreslagna prototypen och det utvecklade konceptet att skilja sig åt på flera punkter.

First of all I would like to thank Filippo Cappadona and Pininfarina S.p.A for bringing me to Italy and allowing me to be a part of the company for six months. This experience means a lot to me and has allowed me to grow both as an engineer and as a person. I would also like to thank Mr Cappadona for being a great supervisor for me and the whole Move-On team for all the support. I would like to thank my supervisor at the Royal Institute of Technology, Priidu Pukk, for the support and both him and the rest of the teachers there for providing me all that knowledge that at the end of my education made me able to do this thesis. Last but not least I would like to thank my family and all my friends in Italy as well as in Sweden for being therefore me!

Sofia Henriksson

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1 Introduction

1.1 Background

In November 2006 the MoveOn project was started. The project is a joint research project for companies within the European Union. MoveOn will run for three years and eight partners from six countries participate. The objective is to investigate the application of a multi-modal and multi-sensor zero-distraction interface for enabling 2-wheel vehicle drivers to access online in real-time and taking into account the road safety issues, services and information [a]. The target user is police motorcyclist and motorcycle riders, specifically the motorcycle police division of West Midlands in the United Kingdom will be considered to be the end-user. The activities of the projects are:

1. The creation of a small to medium-scale spoken language resource (speech copra)
2. Creation of a noise database covering the different driving conditions
3. Robust automatic speech recognition combining head nods interaction under different driving conditions
4. Modular support for multiple modalities through a multi-modal and multi-sensor framework architecture
5. Design of a low cost communications-enabled helmet encompassing state of the art noise reduction features, compliant with helmet manufacturing safety standards, and prototype development
6. Information access and wireless communication environment for motorcycle drivers (nomadic users)
7. Proof-of-concept unobtrusive interface showcased through the use of evaluation scenarios

One of the partner companies is Pininfarina S.p.A an Italian car design company, coachbuilder and product developer situated in Cambiano outside Torino. Within the MoveOn project, Pininfarina is mainly involved in design of the helmet and assembly of a helmet prototype. This thesis researches safety issues in helmet design, concept development of the communications-enabled helmet and guidelines for the helmet prototype.

1.2 Aim

The everyday work of motorcycle police means operating in an environment where the workload can sometimes be heavy and intense. Being on the road on a motorcycle means driving in a non-isolated environment and being in a vulnerable position to the hazards of the road and further more officers will sometimes have to deal with taking in and processing information while driving. The aim of the MoveOn project is to develop an information process system which lowers the workload of the motorcycle polices, processes incoming information and gives them adequate output. The work of this thesis will deal with developing the helmet design to become an integrated part of the MoveOn information environment and develop guidelines for the manufacturing of a helmet prototype to be used when testing the MoveOn system.

1.3 Objectives

The objective is to make a feasible concept for the helmet which can be used for manufacturing of a test prototype for the MoveOn project. The activities will include:

- Concept design of helmet
- Component choice for helmet imaging system
- Material and dimensioning investigation and guidelines for prototype manufacturing

1.4 Limitations

The MoveOn project involves several aspects of speech recognition, building a noise database, framework architecture of the system etc. However this thesis will only deal with the design and feasibility of the motorcycle helmet in which the communication and imaging system will be placed. Other aspects of the project, like the overall function of the system, speech and noise will only be mentioned briefly and where it is directly related to the helmet.

The helmet development will not result in a helmet to be used under real traffic conditions. The work will give guidelines for a prototype, specific for testing the MoveOn system. Homologation regulations will be followed but the helmet concept will have to undertake experimental testing according to ECE-regulation number 22 before being used in real life traffic conditions.

2 Theory

2.1 The protective motorcycle helmet

A protective helmet is defined as a helmet primarily intended to protect the wearer's head against impact. Figure 1 shows a cross-section diagram of a full-face protective helmet. There are some different types of helmets; either with or without visor, either open or full-faced, equipped with chin-guard.

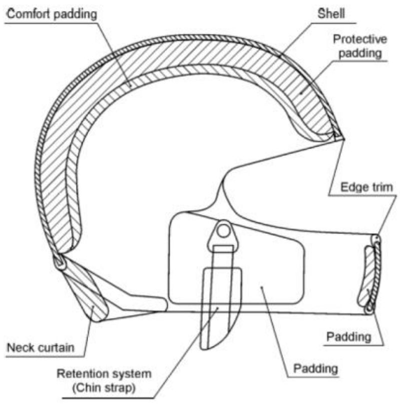

Figure 1 *Diagram of protective helmet [6].*

2.1.1 Shell

The outer shell of the helmet is a hard part that gives the helmet its general shape. The shell is usually made of Polycarbonate (PC), Acrylenitrile-Butadiene-Styrole (ABS) or Fibre Reinforced Plastics (FRP). PC or ABS helmets are injection moulded and FRP helmets are pressure moulded [1]. The six main tasks of the shell are:

1. *Absorbing energy* by bending (PC or ABS shells) or delaminating (FRP shells); circa 30-40% of the impact energy is absorbed of the helmet.
2. *Distributing localized forces.*
3. *Protecting face and temples*; the shell on the chin-bar of a full-face helmet mainly contributes to this.
4. *Preventing fracture of foam liner* (protective-, comfort padding).
5. *Enable sliding against (road) surfaces;* low friction when sliding reduces rotational acceleration on the user's head.
6. *Support other safety components;* the chin-strap and the visor are both attached to the shell.

2.1.2 Protective padding

The protective padding absorbs most of the impact energy. It is most commonly made of Expanded Polystyrene (EPS) which is a closed-cell structural foam [2]; the mechanics of the material allows it to absorb energy at a predictable rate while it crushes. As the foam collapses it absorbs the kinetic energy of the moving head creating only a very small amount of heat. These characteristics give EPS very good impact absorption ability. The structure of the EPS foam varies between different helmets, some having a simple one-piece design, while others consists of several pieces complexly combined. The protective padding is dedicated to [1]:

1. *Give stopping distance to the head*
2. *Protect as much as possible of the head*
3. *Stiffening the helmet structure*

2.1.3 Comfort padding

The comfort padding is the part of the helmet closest to the wearer's head. It is usually made of Polyurethane or Polyvinyl Chloride (PVC) and a layer of cloth. The foam of the comfort padding is much softer than that of the protective padding; hence it absorbs very little impact energy. But it is of utmost importance to provide an appropriate fit for the wearer, testing shows that an ill-fitted and to tight helmet could lead to increase of the resultant translational acceleration in case of impact [2].

2.1.4 Retention system

The retention system is a strap that passes under the wearer's chin, it is made of synthetic fiber or leather and prevents the helmet from rolling off and is attached to the shell by rivets. The chin-strap can also be equipped with a chin-cup.

2.2 Safety

Two-wheel motor vehicles are the most dangerous of all vehicles, the accident rate of motorcyclist are rated to be 15 times higher than that of other vehicle drivers [c]; therefore safety is of utmost importance when designing a motorcycle helmet.

2.2.1 Head injury mechanisms

The human skull consists of 22 bones joined together by sutures of connective bone-tissue and can be divided into the cranium and the face. The 14 bones of the splanchnocranium comprise the ones that support the face. The cranium consists of eight bones from the neurocranium that constitutes the protective vault for the brain and brainstem. Inside the cranium the brain floats in the cerebrospinal fluid, which provides a basic biomechanical protection of the brain as it acts like a cushion in case of an impact. The brain can be divided into cerebrum, brainstem including the medulla and the cerebellum. The cerebrum being the largest part of the brain, the right and left hemispheres, the hemispheres in turn are divided into four lobes; frontal, parietal, temporal and occipital. The brainstem is the connection between the brain and the spinal cord in the lower part of the brain and the cerebellum is situated in the posterior part of the skull (Figure 2).

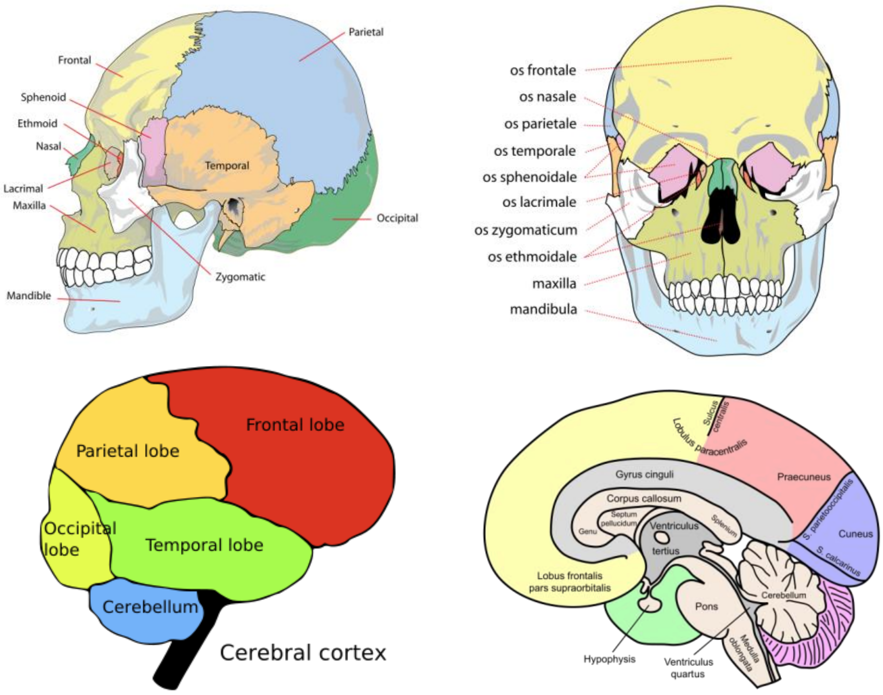

Figure 2 *The human skull and brain (images from Wikipedia)*

When it comes to the biomechanics of head injuries, two major groups can be distinguished; cranial injuries (skull fractures) or intracranial (soft tissue) injuries [3].

Cranial injuries are caused when the load of the skull is greater than the strengths of the cranial bones. A skull fracture in itself does not necessarily create neurological disability. However these types of damages can become mild, moderate or severe if fragments of bone penetrates blood vessels or brain tissue [4]. If the skin of the head is injured the damage is considered to be open, otherwise it is closed, because of a higher risk of infections open cranial injuries are regarded as more severe than closed.

Among motorcyclist the most frequent sort of cranial injuries are basilar, meaning they appear in the base of the skull, these are also more threatening than facial or vault injuries. Vault injuries are also rare among helmeted riders [3].

Intracranial injuries are caused when the vascular or neurological tissues are objected to high strains due to linear or rotational accelerations. Linear acceleration caused by direct blows to the head can lead to brain swelling, bleedings in the brain. Blows to the side of the head are generally more dangerous than frontal blows with the same acceleration level [5]. Rotational acceleration may cause permanent brain damage or concussion at acceleration level of 10000 rad/s.

2.3 Criteria

2.3.1 Head injury criterion

Within automotive injury research the most commonly used criterion is the Head Injury Criterion (HIC). It expresses the severity of an impact as a function both of the intensity and the time duration of the translation acceleration of the head. The definition of HIC is:

$$HIC = \max\left\{ \left[\frac{\int_{t_1}^{t_2} a(t)dt}{(t_2 - t_1)} \right]^{2,5} (t_2 - t_1) \right\} \qquad (1)$$

a is the resultant translational acceleration, expressed in g[1], measured at the centre of gravity of the head, t_1 and t_2 are the two points in time, chosen so that HIC is maximised for the interval.

2.3.2 Peak resultant head acceleration

The peak resultant head acceleration gives a simple measure of the impact efficiency of a helmet and the threshold is expressed in *g:*s for the different standards. The peak resultant is time-dependant and the threshold therefore varies because of different application procedures for different standards. Some of the standards therefore complement the peak resultant head acceleration with requirements for cumulative duration, a peak value that should not be exceeded longer than a certain time interval.

[1] 9,81 m/s^2

2.3.3 Other criteria

The two criteria mentioned above are the most commonly used for quantifying head injury effects of an impact but their shortcoming is that they do not account for rotational acceleration which is believed to cause severe intracranial injuries, like acute subdural haematoma and diffuse brain injury [2]. Efforts have been made to develop an injury criterion which regards both translational and rotational acceleration of the head [2][4].

The Generalised Acceleration Model for Brain Injury Threshold (GAMBIT) assumes that translational and rotational acceleration equally and independently causes injury. Though stated, this criteria has never been validated as an injury criteria. Another criterion that takes rotational acceleration into account is the Head Injury Power (HIP), which treats the acceleration as directionally dependent for the six degrees of freedom. Furthermore; for this criterion it was suggested to weight the change in kinetic energy, for each degree of freedom, since injury sensitivity would vary in the different directions. HIP is only validated for mild injury trauma.

2.4 Homologation

Within the EU it has been agreed to follow standards and testing procedures for protective helmets for passenger and drivers of motorcycles according to the ECE regulation no. 22 [6]. The ECE 22 states standards for fulfillment of two ergonomic aspects:

- The protective areas have to provide adequate cover to fit the head form of the user.
- The shape of the helmet and/or the visor should not impair with the user's field of vision.

Both minimum area to be covered for different helmet sizes and the boundaries for peripheral field of vision is clearly stated in the standard. Furthermore the helmet design has two undertake tests within five areas to be certified:

1. Impact-absorption
2. Projection and surface friction
3. Rigidity
4. Tests of visor

5. Tests of retentions system

2.4.1 Impact-absorption test

The impact-absorption test is carried out in order to determine the impact-absorption capacity. A metal head form is fitted with the helmet, and then dropped under guided free fall at a specific impact velocity (Table 1) upon a fixed steel anvil. The acceleration impaired to the head form is recorded against time and from the result the HIC value can be calculated. The impact is measured in four points (positioned in a specific manner) with an additional point if the helmet is equipped with a protective chin-bar.

ECE-R22-05 Impact-absorption test		
Drop height equal to an impact velocity of…	for helmet measure points (4)	7,5 m/s
	chin-bar measure point (1)	5,5 m/s
HIC		2400
Peak resultant head acceleration		275*g*

Table 1 *Test requirements for ECE-R22-05 impact test.*

2.4.2 Projection and surface friction test

For testing of projection and surface friction two different test methods can be used, A or B. The principle of method A is to drop the helmet and head form vertically on to an inclined anvil. The rotation-inducing forces, caused by projections and friction against the outer shell of the helmet , are then measured along the longitudinal axis of the anvil. The performance criteria (Table 2) are calculated from the integral of the measured peak force with respect to the duration time of the positive impulse.

ECE-R22-05 Projection and surface testing method A		
Drop height equal to an impact velocity of…		8,5 m/s
Peak longitudinal force (test A)	test 1	2500 N
	test 2	3500 N
Time integral of force over duration of impact shall not exceed…	test 1	12,5 Ns
	test 2	25 Ns

Table 2 *Test requirements for ECE-R22-05 projection and surface method A.*

When using the alternative testing method B the rotation inducing forces is created by a shear impact against a shear edge and friction is assessed by the displacement of a carriage rubbing against the outer surface of the helmet. Both of the tests are generated by a drop weight mechanism.

2.4.3 Rigidity test

Before conducting the rigidity test, a solvent is applied to the helmet, and the helmet is then placed in a conditioning chamber and exposed to ambient-temperature and hygrometry (moisture analysis). For the actual rigidity test the helmet is placed between two plates which are either located along the longitudinal axis or the transverse axis. An initial load of 30 N is applied and then increased in sequences, the plates moving at a speed of 20 mm/min, until a load of 630 N is reached and then the load is decreased back to 30 N at the same pace. During on- and offloading the distance between the plates is measured at specific times. At the end of the offloading phase, when the initial state is reached yet again, the deformation is measured and should not exceed 15 mm.

2.4.4 Test of retention system

To ensure that the retention system is suitably durable and that the helmet will come loose, a dynamic force and detaching test has to be carried out.

2.4.5 Test of visor

To ensure that the user’s vision is not limited in such a way that it affects safety and security a helmet fitted with a visor has to undertake test and live up to stated requirements for: field of vision, transmittance and diffusion, refractive powers, mechanical characteristics, optical qualities and scratch resistance.

2.5 Aero dynamics and aero acoustics

Noise is an ever present problem for motorcycle riders, and professional drivers like couriers and motorcycle polices may often be exposed to noise level considered to cause damage [7]. In order to localise sources of noise and vibration, and to find out how aero dynamic forces act on the helmet experimental tests and numerical analysis, such as computational fluid dynamics (CFD), can be used. A combination of experiments conducted in a wind tunnel and CFD can determine how aero dynamic lift and drag might act on the helmet. The result can in turn be used to refine the shape in order to decrease these forces and also to find optimal positions for air intake and outlet holes [8].

Tests conducted by ISVR Consulting in collaboration with police motorcycle officers [9], show that the most significant factor contributing to the generation of noise affecting a motorcycle rider is the bike’s windshield. Depending on height and angle of the windshield, the turbulence caused by it will hit different parts of the rider’s body and the helmet, thus the generation of noise and transmission paths to the riders ears, via the helmet, varies. Motorcycle police officers usually prefer a windshield adjusted so that the edge of it is a few centimetres below eye level, this allows them to glance just above the optically poor windshield. Under this condition the turbulent zone becomes directed at the top of the visor and therefore sealing the visor and isolating it from its hinges and also place damping isolation in the forehead region of the helmet may reduce noise caused by the turbulence. Test shows that noise can be reduced by 6-9 dB using these methods[7]. Other options for noise reduction are the use of earplugs or muffs equipped with active noise reduction (ANR) system. Earplugs have proven to be efficient in reducing noise; a reduction between 8 to 16 dB can be achieved. ISVR’s tests of active noise reduction muffs showed a reduction of 12 to 13,5 dB of the A-weighted levels in comparison to when the original, light-weight muffs supplied with the helmet were used. However, when the ANR-muffs were fitted into a conventional helmet little effect was attained, probably due to a lack of isolation from contact with the helmet shell.

3 Methods

3.1 Requirements and function analysis

To create a basis for analysing the desired characteristic of the helmet information stating the current working conditions for the end-user will be studied; this involves studies of: current equipment used by West Midlands motorcycle police officers, scenarios for situations encountered during service and the user-requirements. Thereafter the function analysis phase starts where desired functions of the helmet will be listed, classified and divided into categories [10].

3.1.1 Classification

The different functions will be classified as:

Main function:	The primary function of the product
Necessary:	Functions the concept must obtain to be useable, attractive and possible to manufacture
Desired:	Functions that not is not necessary but add extra value
Unnecessary:	Not useful functions

3.1.2 Categorising

To make the analysis more perspicuous the functions can also be divided into categories:

User-functions:	The intent of the product and stated requirements
Security:	Homologation and regulation requirements
Ergonomics:	Human factor and capability aspects
Design:	Technical criteria and requirements of materials
Prototype:	how to manufacture/assembly/rationalize the prototype

Some functions may appear in several of the categories.

3.2 State-of-the-art analysis

State-of-the art, in terms of aerodynamics, noise reduction, comfort, safety and helmet-communication systems, and helmets will be studied, but also state-of-the art components suitable for the helmet concept.

3.3 Concept evaluation

When the thesis project began, three conceptual designs had already been developed, thus the initial idea-generating phase had already been conducted as well as the forming of conceptual helmet design proposals. Three different methods were used for evaluation:

- Meetings with helmet OME Nolan
- Pugh evaluation matrix
- Feedback from end-user

3.3.1 OME meetings

The meeting with the helmet OME will be held in order to get feedback on the concept and their feasibility.

3.3.2 Pugh evaluation matrix

The Pugh matrix is a criterion based method for conceptual selection. Concepts are evaluated against requirements and are scored on how well the characteristics of them correspond to the requirements [d].

3.4 Mock-up

For the concept scoring the highest in the evaluation, computer aided styling (CAS) will be used to create a mathematical model. This work will be conducted by a consultant with experience in helmet modelling, and during the CAS-process design and style features will be discussed to determine the shape of the helmet shell. From the mathematical model mock-ups will be milled from polyurethane foam. The mock-ups will be used to present the concepts to the end-user, but they could also be used for aerodynamic evaluation in a scaled wind-tunnel.

3.5 Choice of materials and dimensioning

Materials will have to be chosen both for the shell, the protective padding and the comfort padding. The material choice and dimensioning will be based on studies of suitable materials from aspects such as protective capabilities, durability, manufacturing methods, density and strength.

The method used will be based on *"Selection by Analysis",* an analytic approach to materials selection [11]. In detail the analysis is set-up by answering four questions:

- *Function:* What does the part do?
- *Objective:* What is to be maximized or minimized?
- *Constraints:* What non-negotiable conditions must be met?
- *Free variables:* Which control variables are we free to adjust?

Two different methods, based on an energy absorption analysis approach, will be used to compare different foam types and densities. Result from numerical and FE modelling and experimental testing performed by others will be regarded but no independent model or testing will be performed within this thesis.

3.6 Testing

The MoveOn helmet prototype will be developed with specified testing scenario, defined to evaluate the whole MoveOn system, in mind. The testing scenario will be defined within the MoveOn consortium.

4 Result

4.1 Requirements and function analysis

4.1.1 Equipment used by motorcycle police officers

Within the project timeframe, the MoveOn consortium aims at developing a helmets concept which fits with the requirements of the West Midlands motorcycle police, who represents the final end user.

The equipment currently used by the West Midlands police motorcycle officers consists of: a full face or a flip top helmet (Shoei XR1000 or Shoei Synchrotec), outer garments, communication radio, headset with hand control and a bike handle bar mounted control to use whilst mobile. There is no communication device integrated in the helmet. The radio and the headset are connected via the hand control unit, which is then connected by a jack plug to the motorcycle, also allowing connection between the radio and the control mounted on the handle bar. Both the hand control and the control mounted on the handle bars have a push-to-talk (PPT) button, an emergency button allowing broadcast to all receivers and a volume control. Since the radio is not waterproof it has to be carried inside an outer pocket on the officer's jacket, the cables hanging out and the hand control attached to the jacket with a clip. The headset unit consists of two earpieces with a microphone attached to one of them, the earpieces are supposed to mould themselves to the wearer's ear giving each wearer a personal fit.

4.1.2 Current issue regarding communication devices

The following concerns, in comparison to the current communication system have been expressed by the end user:

1. The equipment is not waterproof;
2. There is no Bluetooth capability;
3. While on the move, changing between different channels on the radio equipment is difficult;
4. There is no easy way of accessing favourite channels;
5. The driver is not able to control volume without moving hands from the bikes handle bars;
6. The system consists of too many kits and there are too many cables;
7. Radio cables are not durable and often cracks;
8. The emergency buttons are sometimes pressed by mistake;
9. Earpieces are uncomfortable and sometimes causes disposition to ear infection;
10. The hand control can neither be operated with glows on, nor on the move;
11. The officer is not able to push the emergency button if both hands are busy;
12. The ear pieces of the head set unable officers to hear a conversation and have to be detached from the ear in order to hear and are then left dangling from the cables;

4.1.3 Component requirements

To build the MoveOn communication system the following constraints are set on the helmet design:

- The volume of the helmet must be shaped to incorporate:
    a. an embedded video camera;
    b. a GPS antenna

c. a plug (or several combined into one).

- Inner shape must be sculptured to integrate
    a. 4 microphones;
    b. 1 earpiece;
    c. small lighting led indicators positioned around the eyes to convey signal to the officer;
    d. a processing unit;
    e. batteries;
    f. cables.

The components also require a certain placement to ensure the functionality of the system. The embedded camera has to be placed parallel to the viewing direction of the helmet wearer's eyes. Because of the noise environment, microphones and headset have to be placed close to the wearer's mouth respectively ears. LED-indicators must be placed in the periphery of the wearer's sight where they can be easily detected, yet do not distract the wearer; hence the chosen position is just above the eyes at the corner of the helmet opening. The GPS antenna should be located directly beneath the helmet shell to ensure performance optimization and to be able to detach the device. Components and their expected dimensions are presented in appendix B and their suggested placement is shown in appendix C.

4.1.4 Functions

Even though the MoveOn-project aims to develop a multi-modal communications helmet the most important function of any helmet is to protect the wearers head, in this case from impact in case of crash, thus protection from impacts against the head is determined to be the main function.

Integrating components for the communication system is considered necessary. Ergonomic and safety aspects were considered important groups of functions and were therefore assigned a function analysis each, as well as necessary functions considering prototype assembly. The design function analysis determines the necessary characteristics of the different parts of the helmet. The complete lists from the function analysis are presented in appendix A. The determined functions will then have to be transformed into parameters and characteristics which fulfil the requirements. In other words appropriate materials, capable of fulfilling the functions, and material characteristics, such as density and stress and strain capability, must be established.

4.2 State-of-the-art

This part will treat state-of-the-art helmet system concepts. The aim is to investigate helmets Bluetooth systems on the market and other innovative devices that apply to motor cycle helmets.

4.2.1 Helmets

During the last few years helmets, that offer the motorcycle rider more than merely head protection, have started to emerge on the market. The innovations provide the rider with the ability to communicate and receive information, and increases safety and comfort. Helmet manufacturers have started to provide helmets with integrated modular communication systems, that use Bluetooth technique to enable wireless communication with equipment such as mobile phones, GPS-units and portable music players, and also between two drivers or between driver and pillion rider. The latest developments of the market will be presented below.

Nolan has integrated the N-Com communications system (Figure 3) into their product range [e]. At its most advanced, the system provides communication, to mobile phones and intercom, wireless through Bluetooth, while to connect a GPS or a portable music player or to make bike-to-bike communication, a multimedia wire accessory is required. The user controls the system by pushing the three buttons on the e-box, situated on the left side of the helmet, either one at a time or in different combinations and for different time spans (2-4 sec) to activate certain commands (volume adjustment, changing between communication source).

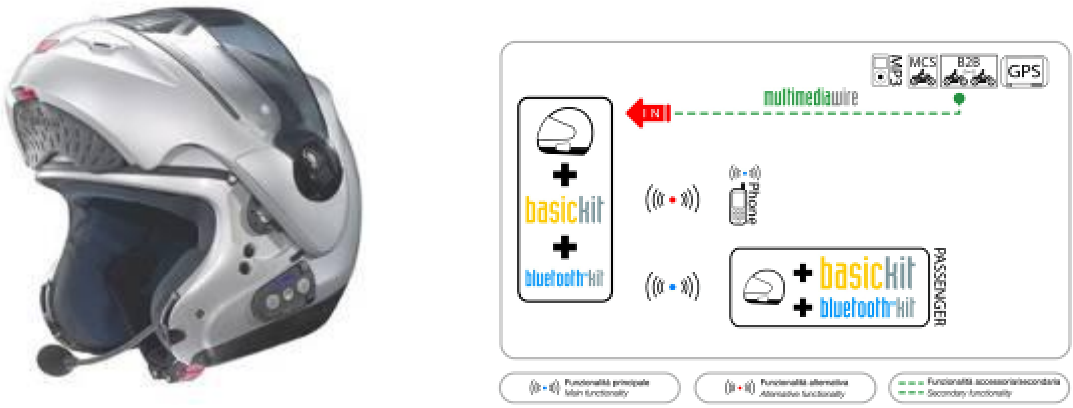

Figure 3 *Nolan Classic N-Com helmet and N-Com system [e].*

In 2005 BMW introduced the BMW System V helmet (Figure 4) with the WCS-1 wireless communications system [f][g]. The system provided Bluetooth communication to mobile phone, GPS-navigator and music player, and had a system of two microphones and speakers, equipped with a digital signal processor to filter out interference and cancel wind noise. The WCS-1 system was cancelled on the market due to functional issues, but BMW is said to be working on a new system to be introduced in 2008. The System V helmet itself is still on the market, and has an aero acoustically optimised design and a selection of advanced materials (Kevlar®, carbon fibre and glass fibre) to lower the level of noise that reaches the motorcycle rider. Wind tunnel tests show that the level of noise inside the helmet measures up to 86 dB at 100 km/h, which is an estimated 8-10 dB lower than the average helmet.

Figure 4 *BMW System V helmet [f].*

Another range of helmets with high noise-cancellation ability are the Schuberth S1-series [h] (Figure 5), showing test results equal to the BMW System V helmet. The outer-shell-material consists of either glass-fibre reinforced Duroplast® composite (S1-Pro) or carbon fibre composite (S1-Carbon). The design is optimised to reduce noise and the helmets are also equipped with an acoustic collar to reduce noise caused by turbulence around the neck and shoulders of the rider.

Figure 5 *Clockwise from the upper left: Shuberth S1-Pro, S1-Carbon and acoustic collar [h].*

Schubert has also tried to integrate the Bluesonic system that, through Bluetooth, enables wireless communication; between two helmet systems, to a mobile phone and to the bluesonic Motostation [i]. To the Motostation a radio, for communications with others riders, a music player or a navigator can be connected. When the navigator is connected to the Motostation the driver will be able to receive voice announcements, for example driving directions, via the integrated headset. The microphone, installed inside the helmet, includes voice operated transmit (VOX) and the radio communication can be controlled by a push-to-talk key (PTT).

Figure 6 *Schubert helmet system [i].*

4.2.2 Devices

For many years, peripheral displays have been used in military combat equipment, for example in air pilot helmets to enable the pilot to see instrumental data without having to move the eyes from the line of flight to the instrument board. Two examples of head-up displays (HUD) have been introduced to the market recently; the Reevu helmet with a 180-degree rare view system [j] and the Sportvue HUD [k] working with the Veypor motorcycle performance gauge [l].

The Reevu helmet has a system of mirrors that displays a 180-degree vision of the rare view of the driver on a HUD (Figure 7). Since rare view mirrors, mounted on the bike, often provide poor vision for the motorcycle driver, due to vibration and limited field of vision, the more stable picture given by the Reevu system enhances the safety of the driver. The mirrors are made out of ABS, giving a robust system at low costs.

Figure 7 *Reevu system helmet and driver's view of the display when wearing the helmet [j].*

The Sportvue HUD (Figure 8) is developed to provide the rider with data, such as speed, rpm and gear, collected through the Veypor performance gauge. The Sportvue HUD communicates with the performance gauge through a RF-sender unit and the data are displayed at the upper side of the rider's helmet.

Figure 8 *Sportvue HUD on helmet and driver's view of the display [k].*

Two one-of-a-kind helmets have also been developed. The first being the Schubert RF-1 helmet, that was customized for F1 driver Michael Schumacher with a miniature HUD developed by BMW [m] (Figure 9). The display is able to show high-resolution true colour due to technique based on an active matrix liquid crystal display (AMLCD) and using lens elements, known as free form prism (FFP), the image is claimed to become very clear.

Figure 9 *Customised Schuberth helmet with miniature HUD [m].*

The second helmet (Figure 10) was developed by Piers Tucker, a degree student at the Brunel University, and was presented in 2004 [n]. This helmet also holds a HUD, the display unit consisting of a LCD. Movement is calculated by a GPS-chip and converted from nautical speed into mph, and information about indicators and gear is given by radio transmitters.

Figure 10 *Helmet with HUD by Piers Tucker [n].*

4.2.3 Summary of previous state-of-the-art research

A couple of different helmet Bluetooth systems has been introduced during the last few years, but, as with the BMW WCS-1 system and the Schuberth bluesonic, problems have emerged when launched on the market and the systems have been withdrawn for further development. As for now, Nolan N-Com is apparently the only helmet system to be sold. There are also several Bluetooth head-set solutions (like Scala Rider FM), to enable mobile phone calls and listening to FM-radio, to use with any kind of helmet. Also noticeable is that there is no international standard for Bluetooth and for such equipment, therefore Bluetooth equipment from different manufacturers may not work together. When it comes to noise reduction, BMW and Schuberth provides the helmets showing significantly lower noise levels than standard helmets, when tested in a wind tunnel. Though it had to be said, that results of such a test is heavily depending upon the placement of the bike's windshield, because of the turbulence created by it, and therefore noise levels can be higher while riding some type of bikes [7]. So far no helmet with a really sophisticated VOX-system seems to have been developed. HUD devices are on the market and able to provide riders with basic data, though not for sale, the most advanced example, in terms of image quality, is the BMW miniature HUD.

Previous state-of-the-art research shows that the individual components for the system are all available on market as separate products. The challenge, however, is to successfully integrate them into working as one system.

4.3 Helmet concepts

Prior to the start of the thesis work the Pininfarina research and development department and the styling department cooperated to develop concepts for the style of the helmet. These three concept was a style study made by an industrial designer and was later used as a basis for the helmet concept development. The design criterion was based on the requested components to be integrated in the helmet and their possible placements (appendix B and C). Three different concepts were developed A (appendix D), B (appendix E) and C (appendix F). The style of the helmet should convey an idea of safety and authority while still keeping a friendly aspect, therefore the style, of all three proposals, has a clean and strict look with the visor closed but also a front flip-top, to be openable in order to let the police officer show his face and make “human contact”. Inspiration was gained from different helmets used; in space, in war, in racing, in movies, for motorcycle riding and the everyday work of police officers.

All three proposals have also been styled to fit the required devices, but since it is of utmost importance to keep the helmet light, the devices have been kept at a minimum and therefore the idea is that the batteries, to supply electricity for the devices, should be stored in a vest. In all three proposals a connection between helmet and vest (or neck-protection system) is suggested in the back of the helmet. Proposal A has a full front visor, while B and C has a lower face cover providing additional protection. The devices were placed for optimal aero dynamical, minimizing aero acoustic noise. The placement of the camera differs between the three helmets. In proposal A the camera is placed on top of the helmet, the camera being able to take pictures with the visor opened. For proposal B the camera was placed in the lower front of the helmet, inspired by the placing of oxygen tube intake in astronaut helmets. And for proposal C the camera was placed on the side of the helmet, a common placement of helmet cameras and camcorders on the market.

4.4 Concept evaluation

4.4.1 Meeting with OME Nolan

In order to deepen the knowledge and take part of the experience from an established helmet manufacturer, meetings with Italian company Nolan was arranged. The following section is a summary of the knowledge gain from the meetings. The first meeting was held in November of 2007, prior to the start of the thesis-project, but is described in this section to give a coherent summary of the contact with Nolan.

Summary of the first meeting: The estimation for the annual helmet sales addressing the Police Force determined a small number of perhaps 5000 helmets per year. This represents approximately 1% of the overall helmet sales for NOLAN. The manufacturers also highlighted that each new helmet has a life-cycle that succeeds a sales target between 500.000 and 1.000.000 pieces in the market.
Different manufacturing alternatives were described in detail clarifying that there are two options with respect to applicable materials:

- The first option referred to as “X-Lite”. In this case moulding the prototype represents a moderately lower cost but production proves very expensive. Helmets in this category address mainly the racing market.
- The second option refers to the polycarbonate plastic helmet whereby producing the moulded model represents a relatively expensive process, nevertheless production proves relatively in-expensive.

From the presentation it became apparent that in order to produce the MoveOn moulded model it is necessary to proceed to a hand-made prototype for addressing the market approval. It is probable that the MoveOn model fits better under the second option.

Additional data were provided referring to the optimal weight of the helmet without the accessories. This should be between 1,7 to 1.8 kg. The overall weight normally should not exceed 2.0 kg (with all the accessories listed in appendix B). A very interesting detail for the manufacturing process concerns the sizes. The general practice defines that the external helmet is produced in only one size matching the XXL standards. The smaller sizes are achieved by the accessory of garments. This defines increased security for the smaller sizes as there is additional space between the head and the helmet. The discussion continued in a brain-storming manner focussing on innovation possibilities in the technology and manufacturing fields. Subjects covered the possibility to embed solar energy receivers on helmet to satisfy the lack of battery capacity. Issues such as flip internal & external visors and embedded Bluetooth technologies have already been implemented commercially. MoveOn should link to the existing latest models in production, for example the N-Com technology helmet may be used as a baseline to proceed with the prototype.

Summary of the second meeting: For consulting OEM NOLAN about the design of the helmet a second meeting was arranged at Pininfarina. The discussion revolved around different types of helmet design solution which could enable the helmet mounted camera to photograph at any time, for example with the helmet visor open.

Figure 11 *Left: open-faced helmet, Right: Full-face, flip-up helmet*

There are two different main types of helmets. The open face helmet (Figure 11), also called, jet helmet, and the full-face helmet (Figure 11), which can either have a fixed lower-face protection part or a flip-up lower-face protection part. The open face helmet has a lower weight, but it is less safe because it lacks the lower-face-protection part. The full-face helmet is heavier but offers total safety. Analysis of the helmet design concluded that with a full-face, flip-up helmet camera visibility could be difficult to receive with the visor opened.

The solution for a helmet design, where the helmet camera is placed on top of the helmet and is still able to photograph at all times, could be a combination of the two helmet types. This combination would be an open face helmet equipped with a safety chin-guard. The chin-guard is a protective lower-face part, smaller than the one of a full face helmet, usually a hoop of metal (Figure 12). Thus the helmet is lighter than a full face helmet but with the visor closed it offers total safety, equal to the full face helmet. It also offers an enhanced visibility, compared to a full face helmet, since the entire face part is transparent. The visor can be made big enough to pass over a camera placed on top of the helmet when open.

Figure 12 *Jet helmet with chin-guard hoop*

Also, suitable materials for the manufacturing were discussed for such a helmet. Helmets are usually made either using injection plastic (ABS/polycarbonate alloy) or from fibre-composite but a mix of both manufacturing methods could be suitable for the open face helmet with chin guard. Main part of the helmet shell could be made out of composite while special parts, for example to cover the camera, could be made out of plastic. The chin hoop could be made out of titanium to keep it light yet strong. Visor material could be polycarbonate with good transparency and toughness.

Summary of the third meeting: A third workshop was held between the Pininfarina MoveOn team and helmet OME NOLAN. The subject discussed was the helmet styling proposals realized as a milled prototype. The following aspects were treated and evaluated:

- Over-all style and shape of the helmet;
- The feasibility of the concepts: the possibility to combine the different camera placements, on-top or lateral, with a full-face helmet with lower-face cover;
- The kinematics of the lower-face cover for a helmet equipped with a camera on-top;
- Manufacturing alternatives for the concepts.

The over-all style and shape of the helmet was well approved of. Of the two concepts, lateral- and on-top camera-placement, the lateral was considered easier to realise since already design kinematics can be applied on the moveable lower-face cover. For the top-camera concept some sort of sliding mechanism and/or a split lower-face cover will have to be engineered to allow lower-face cover and visor to not impair with the camera whilst opened.

The helmet will sometimes be used in such an environment that it will be exposed to heavy rain, dust and possible rough handling. Either concepts have to make sure that camera or other devices are properly protected. For the lateral-camera-concept there are risks of damage because the camera sticks out of the helmet shell. The top-camera-concept, on the other hand, may require good isolation of the modular pieces in order to avoid water to penetrate to connections.

4.4.2 Concept modification

Based on the research from the helmet style concept A, B and C three different concept 1, 2 and 3 was developed:

1. A full-face helmet with flip-up visor an camera on top (a combination of original concept A and C);
2. A full-face helmet with flip-up visor and camera mounted on the side;
3. An open faced equipped with visor and chin hoop and camera mounted on the top.

These three concepts went on to be evaluated.

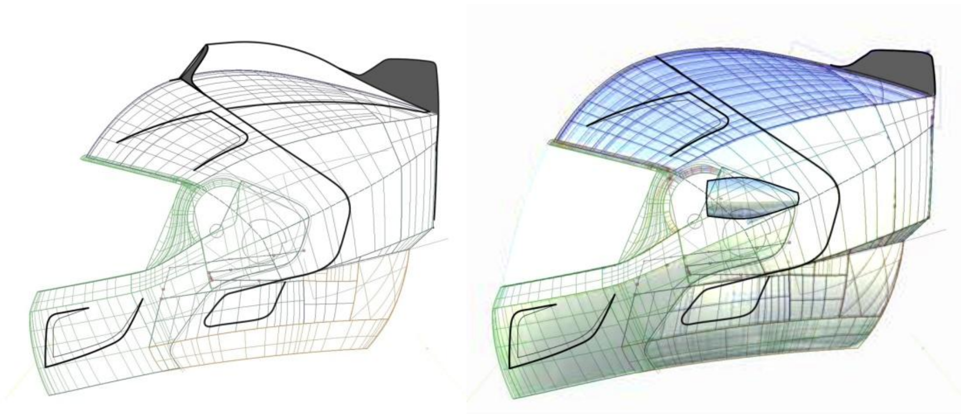

Figure 13 *Helmet concepts 1 and 2*

4.4.3 Pugh's evaluation matrix

The criteria, against which the concepts will be evaluated, were formed on the basis of the function analysis and the requested function was transformed to fit the evaluation matrix. The criteria were then weighted with numbers between 1-5, where 5 is given to the most important criteria. Safety and aero acoustic abilities were judged to be important and were given 5, while standard manufacturing was not regarded important since the concept initially aims to be produced as a one-of-a-kind prototype. The whole matrix is presented in appendix A. The result of the concept evaluation resulted in the highest scores for concept 1.

4.4.4 Mock up

Based on the matrix evaluation concepts 1 and 2 were judged the strongest. These two where then mathematically modelled and milled to a mock up (Figure 14), which was presented to the project consortium and representatives of the West Midlands police. Comments on the concepts concluded that concept 1 was favoured because of its ability to host the camera within the helmet shell.

Figure 14 *Mock-up of helmet concept*

4.4.5 Final choice

The overall concept evaluation, from evaluation matrix and user-feedback, led to the conclusion to proceed with the development of concept 1. It is favoured by its protective capabilities and the ability of integrating the MoveOn-system. The concept proceeded to definition of components and dimensioning.

4.5 Helmet camera system

One of the key components in the MoveOn system is the embedded helmet camera. The imaging part of the MoveOn system can be regarded as a machine vision system. A machine vision field can be described as:

“The use of optical sensors to automatically receive and process images of real objects, with the purpose to gather information about the objects, govern mechanical equipment and/or control processes.” [13]

Basic execution steps are the same in every machine vision system [14]:

1. Image collection: An imaging system acquires the images and converts it to digital form via sampling;
2. Image processing: With the help of software codes, the processing unit uses different algorithms to analyse the collected image, and the desired image processing is executed;
3. Control and action: Finally the processing unit interprets the result from the image processing and sends signals of implementation of appropriate actions to the related equipment.

The components of a typical machine vision system consist of:

a. Illumination system;
b. Imaging system: lens, camera and framegrabber;
c. Processing unit: computer;
d. Related executing equipment: This performs adequate actions implemented by the processing unit. For example a robot.

For the MoveOn system the corresponding specification for the execution steps and components can be made:

1. Images to be collected: Suspect persons or objects (vehicles)
2. Image processing to be executed: Analysis of human face or vehicle number plates, compare to database;
3. Controls to be made and actions to be carried out: Display information about suspect person or object to policeman.

a. Illuminations system: Day-, vehicle- or streetlight;
b. Imaging system: Helmet camera system;
c. Processing unit: On-vehicle-PC;
d. Related executing equipment: Display of information by HUD or speech.

Only the helmet camera system, lens, camera and framegrabber, will be chosen here since other partner in the consortium will design the rest of the system. However the specifications of imaging system are depending on all of the other components of the system. The camera sensor has to be sensitive enough to deal with available illumination conditions and there has to be a convenient interface between the camera and the main processing unit.

4.5.1 Illumination

It is common to provide machine vision system with a customized illumination system, since appropriate lightning conditions can improve the imaging systems performance immensely. In the case of the helmeted camera system it is not difficult to design a specific illumination system since the environment and its lightning conditions is not fixed. However the camera system will be aided by light sources that are already present in the environments surrounding it; daylight, spotlights from vehicles and streetlight. The illuminance of each of these sources it stated in Table 3:

Light source	**Illuminance [lux]**
Direct sunlight	32 000 – 100 000
Day light	5000 - 10 000
Street light	10 – 20
Motorcycle headlamp	~ 40 – 200 [2]

Table 3 Approximate illumination for light sources in the operating environment.

4.5.2 Processing unit

The imaging system will send the collected images to a main processing unit (MPU) that will have the ability to analyse the data. For the MoveOn system the main processing unit is an ultra portable computer or personal digital assistance operating on suitable operative system, for example Windows XP.

4.5.3 Executing equipment

After the vehicle-embedded Pc collected the images from the imaging system it will process the info and pass back feedback to the policeman via the information system,

[2] This is a rough estimation considering a headlamp with an intensity of 24 000 cd (minimum ECE-regulation requirement) at a distance of between 25 and 10 meters and the angle to the illuminated point is 0.

for example display and/or microphone system. It might be information on the owner of a suspect vehicle.

4.5.4 Imaging system

The MoveOn imaging system of a camera with appropriate lens, specified so that required image quality will be obtained. There are four fundamental parameters of the machine vision imaging system:

- The field of view (FOV): The object area captured by the lens and projected on the image sensor;
- The working distance (WD): The distance between lens and object;
- The depth of field (DOF): The largest distance difference which still able the imaging system to keep focus;
- The sensor size: The size of the active area of the sensor.

Then the image quality depends on several factors:

- Resolution: A measurement of the system ability to reproduce details;
- Contrast: The normalized difference in intensity between dark and light areas;
- DOF;
- Distortion: An optical error caused by the lens resulting in magnification differences between different points in the picture;
- Perspective errors/ Diffraction

The first step in determining the performance of the camera system is to specify the FOV, both in horizontal and vertical direction. The purpose of the imaging system is to capture images of suspected persons and vehicles. One scenario might be to film a suspect along with their vehicle (Figure 15), from this scenario the necessary maximum FOV is defined to be 3 times 3 meters. The required sensor resolution can be calculated by using equation (2).

$$sres = \frac{FOV}{size\,of\ smallest\ feature} \cdot 2 \qquad (2)$$

It is decided that the sensor has to be able to capture object features of at least 10 mm. Equation (2) then yield that the minimum sensor resolution has to be 600 pixels in each direction.

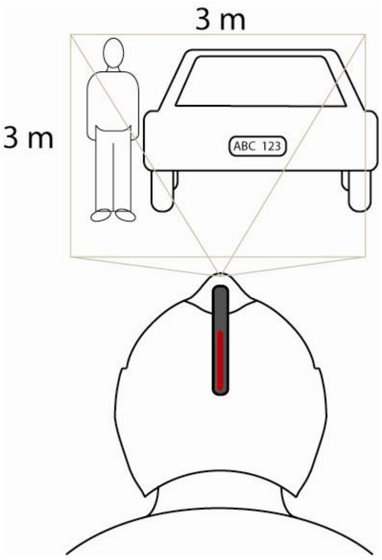

Figure 15 *Field of view of the user-scenario*

4.5.4.1 High speed applications: Scanning, sensor and shutter type

The MoveOn system will also have to capture fast moving objects, for example a vehicle travelling 90 km/h past an officer parked at the roadside. The image quality of a captured fast moving object depends on the type of camera used, or specifically what technique the camera uses to scan the picture, and image sensor and shutter type, which affects the exposure time of the sensor.

Due to economical reasons traditionally television cameras have often been used in machine vision systems [15]. CCTV camera exposes and also transfers data in an odd and an even field of lines interlaced to each other. In high speed applications this may cause motion tear in the image (Figure 16).

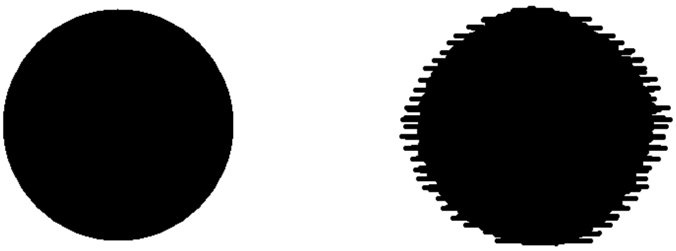

Figure 16 Sharp image vs. image with motion tear

By using equation (3) the motion tear can be calculated for a certain application.

$$MT = \frac{V_o \cdot T_F \cdot N_{pH}}{FOV_H} \tag{3}$$

V_o is the object velocity

T_F is the time for each image field

N_{pH} is the number of pixels in a scan line

FOV_H is the FOV horizontally

For CCTV cameras the time for each image field is half the exposure time, which in standard cameras is 1/30th of a second. If the MoveOn system would use a CCTV camera the object velocity is set to 90 km/h for its high speed applications, time for each image field is 0.0167 s, number of pixels 600 (as calculated before) and field of view 3 m. Equation (3) then gives:

$$MT = \frac{25000mm/s \cdot 0.0167s \cdot 600}{3000mm} \approx 84\,pixels$$

The motion tear for the MoveOn high speed situation would stretch over 84 pixels or more than 1/7th of the image, if a standards CCTV camera is used and this would provide a poor image quality. To eliminate the effect of interlaced motion tear progressive scanning could instead be used. This type of technique is used in digital cameras, and unlike interlaced scanning the image is not split into two fields but scanned in one complete frame. The gain in image quality using progressive scanning, instead of interlaced, when filming a moving vehicle is shown in Figure 17.

Figure 17 *Progressive versus interlaced scanning filming a moving car [o].*

Another phenomenon that occurs when shooting fast moving objects is image blur (Figure 18 a). Image blur occurs when the object moves during the time that the sensor is exposed. The blur caused by an object moving at certain speed shoot can be calculated using equation (4).

$$B = \frac{V_o \cdot T_E \cdot N_p}{FOV} \tag{4}$$

V_o is the object velocity

T_E is the time of exposure

N_p is the number of pixels spanning the field of view

FOV_H is the field of view size in the direction of the motion

Generally a blur of 1 pixel can be tolerated; equation (4) can then be used to calculate the required exposure time for an object velocity, FOV and sensor size. For the MoveOn project the exposure time would be:

$$T_E = \frac{B \cdot FOV}{V_o \cdot N_p} = \frac{1 \cdot 3000mm}{25000mm/s \cdot 600} = 0{,}0002s$$

The standard exposure time of a CCTV camera is 1/30th of a second; the calculated exposure time would be 1/5000th. However this problem can be solved by using a high speed electronic shutter. This can significantly reduce exposure time and thus image blur. The most effective electronic shutter type is the true global shutter usually found in the sensor type called interline-transfer charged-couple device (IL CCD). This shutter type can be compared with the rolling shutter usually used by the other common type of image sensor: complementary metal-oxide semiconductor (CMOS). Figure 18 shows the effectiveness of a true global shutter compared to no shutter, rolling shutter and inefficient global shutter.

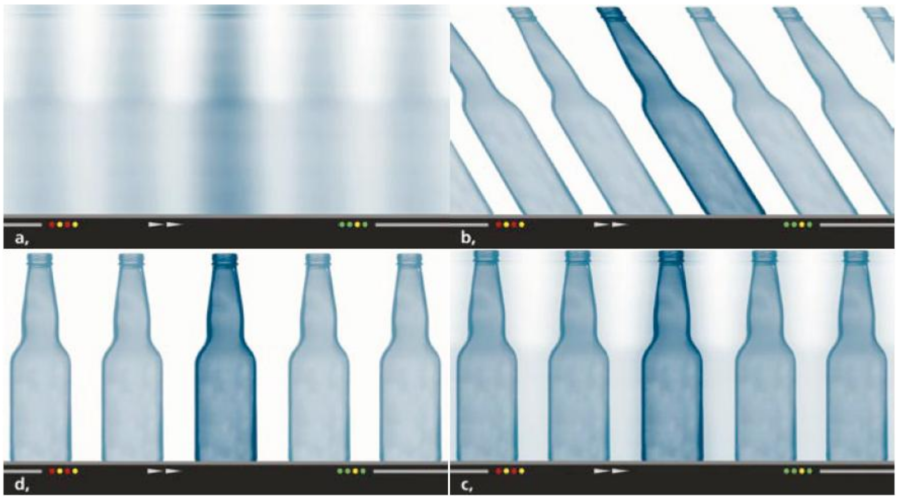

Figure 18 *Fr top left clockwise; a, Motion blur (no shutter or to long exposure time) b, Rolling shutter c, Inefficient shutter d, High-performance true global shutter [16].*

4.5.4.2 Lens selection

The selection of lens for the camera depends on:

- How the lens should be mounted;
- Sensor size;
- Size of and distance to object;
- Light conditions;
- Type of lens (fixed focus, zoom).

One crucial factor for the MoveOn system is the lack of space available to accommodate the camera. This means that a camera as small as possible need to be used. This will affect the lens mount to be preferred and also the size of the image sensor.

There are three ways of mounting the lens to the camera board; the C-, CS- and M-mount. The required distance between sensor and lens is; 17,5 mm for C, 12,5 mm for CS and 12,5 mm or smaller for M. Since CS- and M- mounting requires less space they are to be preferred.

Since the camera needs to be small the image sensor also needs to be so. Sensor sizes are standardized the smallest format being 1/4". The dimensions of this sensor are 3,2x2,4 mm. The trade off with a small size sensor is a loss of image quality. The next sensor size has format 1/3”, having dimensions 4,8x3,6 mm.

When choosing a lens for an imaging system the size of the object, the size it is wished to be reproduced in and distance between object and lens will determine the required focal length for the system. The geometry of the system is shown in Figure 19.

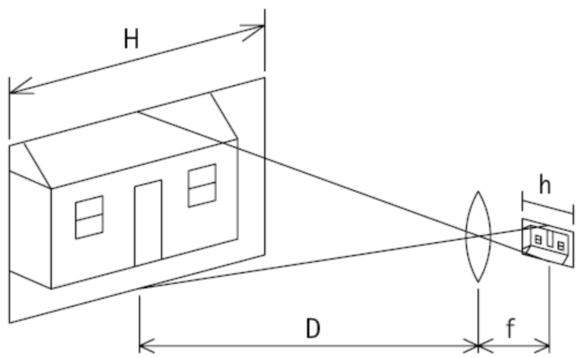

Figure 19 *Geometry between focal length, object- and sensor size and distance between object and lens.*

By using the thin lens formula and assuming that the distance between lens and object is much greater than the image (sensor) size a relationship between the parameters can be formed.

$$f = \frac{h \cdot D}{H} \qquad (5)$$

f is focal length

h image (sensor size) horizontally

D is distance between object and lens

H is object size horizontally

Equation (5) was then used to compare different focal lengths for a 1/4" sensor, by calculating how large that objects could be captured by the sensor at a certain object distance. The result for focal lengths 4, 8 and 25 mm is displayed in Figure 20. To be able to detect the presence of someone at a display they could occupy at least 10% of the image height and to be able to identify them the number is 40%. The plot shows that for a 1/4" size sensor a 25 mm focal length would probably be two long, since possible object width to be captured would be too limited for the application. Both for a 1/3" and 1/4" sensor the focal length would have to be between 4-8 mm to be able to capture the appropriate object width. The best option would be too use an automatic zoom lens, where the focal length can be varied without losing focus. However, due to the limited amount a space a fixed lens will probably have to be the choice.

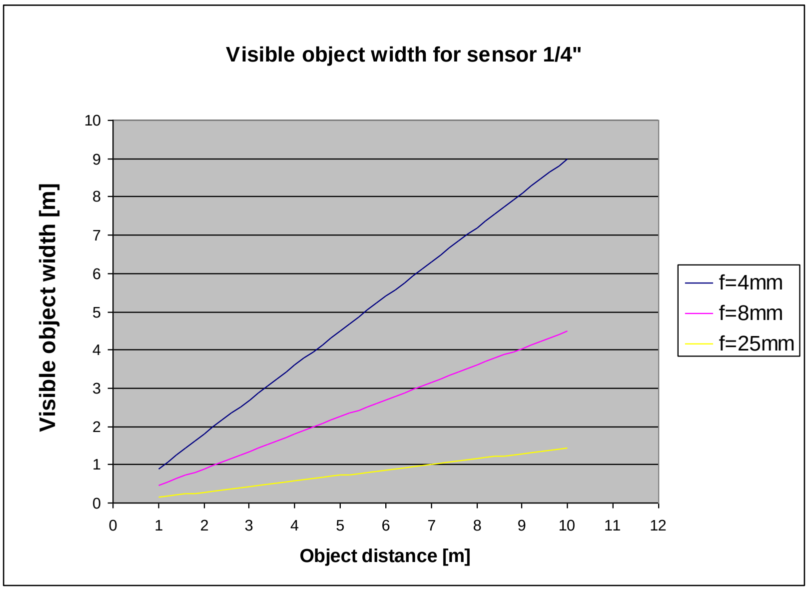

Figure 20 *Visible object for sensor 1/4" and various focal lengths.*

One important part of the camera system is the aperture, which controls how much light that will be allowed to travel to the image sensor. Lens manufacturers usually state the f-stop number of the aperture for a lens with a certain focal length. The f-stop number (f/N or #f) is the ratio between the focal length and the diameter of the entrance pupil. The larger the f-stop number the lesser the light will be admitted to the sensor. A larger f-stop number will also increase the DOF. It is not possible to directly compare the f-stop number between two lenses with both different diameter and focal length.

4.5.4.3 MoveOn helmet camera system definition and choice

From the above it is possible to make conclusions about the required performance of the camera system and state ideal performance characteristics of the camera. The ideal characteristics were then compared to on-the-market devices and imaging systems, until an option close enough to the ideal requirements was found. The list below concludes the demands and Table 4 shows the ideal camera and examples of two cameras found that were considered suitable for the system.

- The sensor type should be IL CCD to allow true-global shutter for enhanced high-speed applications;
- Due to the limited space the sensor should not be larger than 1/3", however this size is preferred to the smallest sensor, 1/4", since the larger sensor most probably will enhance image quality;
- The preferred image scan type is progressive, since this gives better image quality in high speed applications than interlaced scanning;
- The shutter type should be electric to allow fast shuttering and short exposure times for shooting object travelling at high speed;
- Due to limited space for accommodating the camera in the helmet dimensions should not exceed 30x30x50 mm (WxHxD), including lens;
- Lens mount type should be CS or M-12 to save space;
- Sensor resolution should be at least 600x600 pixels;
- The camera has to be able to function with only evening street light-conditions, where illumination could be even lower than 40 lux;
- The weight of the imaging system (camera and lens should not exceed 200 g or the helmet will be too heavy;
- The interface of the MPU is preferably USB 2.0;
- The camera and framegrabber should be able to operate together with an MPU running on operative system Windows XP;

Characteristics	Ideal	Digital	Analogue CCTV
Sensor type	IL CCD	IL CCD	IL CCD
Sensor size	1/3”	1/3”	1/4"
Scan type	Progressive	Progressive	Interlaced
Shutter type	Electric	Electric	Electric
Shutter speed	at least 1/5000	-	1/60 to 1/100000
Dimensions	30x30x50 mm	45x45x40 mm	26x22x16 mm
Lens mount type	CS/M-12	C/CS	CS/M-12
Resolution (HxV)	600x600 (at least)	1034x779	752x582
Minimum illumination	~20-40 lux	9,6 lux (at #f1,2)	<1,0 lux
Weight	200 g (with lens)	145 g without lens	-
MPU interface	USB 2.0	USB 2.0	USB 2.0
Operative system	Windows XP	Windows XP	Windows XP

Table 4 *Ideal camera characteristics for the MoveOn system and options from the market.*

It is clear that the digital camera will perform better than the CCTV in high speed applications and it will also have better image quality because of its larger sensor and higher resolution. On the other hand it is too large to fit the space reserved in the helmet for the camera, and most probably it will also be heavier than the CCTV camera. The consequence of using the larger digital camera would be that the camera would have to be placed somewhere else than in the helmet for the testing of the prototype. Both of the cameras are of board type which means that they have no housing to protect the camera. At the end the smaller analogue camera was chosen despite its lacking image quality; the decision was based upon the fact that for the sake of the prototype it was considered more important to test the MoveOn helmet system as a whole than to receive optimal image quality.

Once the camera was chosen a lens to accompany it would have to be picked. The focal length for the lenses that suited the camera were standardized and since a lens with focal length between 4-8 mm was suitable to require desired object width, there were five different focal lengths to choose from. Finally a M-12 mounted lens with focal length of 4,3 mm was chosen. The complete data for the chosen lens is presented below.

Focal length	4,3 mm
Aperture f-stop	1.8
Diagonal FOV	59˚
Iris	No
Focus	Manual
Back focal length	4,0 mm
Diameter	14 mm
Length	15,4 mm
Minimum object distance	40 mm

Table 5 *Characteristics of the chosen lens.*

4.6 Camera module

The selected camera, lens and camera board, has outer the dimension of 26x22x16 mm and the shell of the camera module will have to be fitted to be able to hold the camera. The camera can be mounted between the front of the shell and a mounting plate (Figure 21). To avoid vibrations to propagate from shell the camera, rubber elements should be placed between mounting plate and camera, possibly also in the mounting in the front of the module.

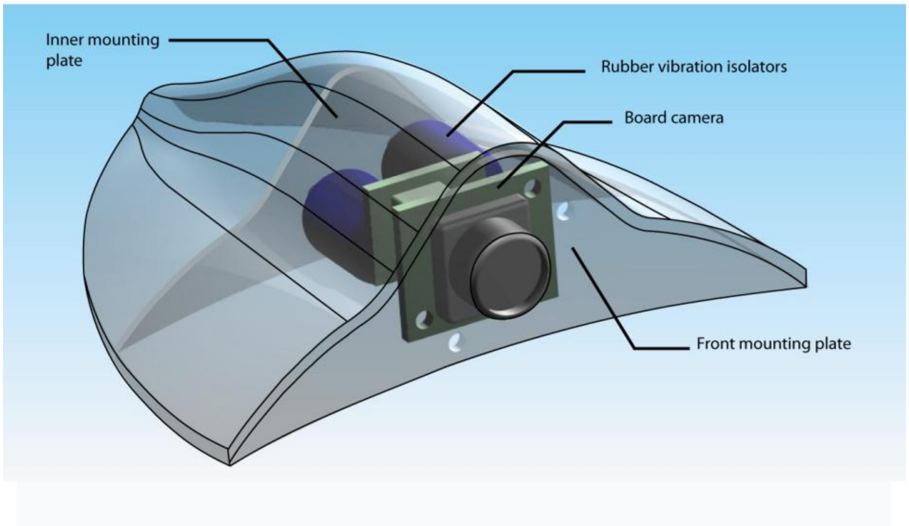

Figure 21 *Camera mounted in shell module.*

The approximate dimensions of the helmet module are shown in appendix H.

4.7 Dimensioning and choice of material

The first step in the selection and dimensioning analysis is to determine the functions of the specific parts: *What do the components do?* In this case the components to consider are two; the shell and the protective padding. From the description of the parts (see section 2.1.1 and 0) and the function analysis (see section 4.1 and appendix A) it is possible to establish the functions of the shell respectively the protective padding. A summary for each part is presented in Table 6 below:

Part	Functions	
Outer shell	Absorb energy	Support MF
	Distribute loads	Support MF
	Provide cover to head and face	Support MF
	Reduce noise	
	Enable sliding	Support MF
	Protect inner parts	
	Store and support components	
Protective padding	Absorb energy	Support MF
	Protect surface of head	Support MF
	Stiffen helmet structure	Support MF
	Store components	
	Reduce noise	

Table 6 *Functions of shell and protective padding.*

Some functions are considered especially important for selection and choices, since they support the main function of the helmet, namely to protect the head in case of impact.

The arising question to answer is: *What should be maximized or minimized?* In this case it is necessary to minimize the total weight of the helmet. The total mass of the helmet is given by:

$$m_{tot} = m_s + m_{pp} + m_c \qquad (6)$$

Where m_s is the mass of the helmet shell, m_{pp} is the mass of the protective padding and m_c is the total mass of the components integrated into the helmet. Every mass should be as low as possible in order to minimize m_{tot}.

Next *the non-negotiated constraints* have to be determined. For a crash helmet the constraints are set by regulations, here the criteria impact-absorption drop test from UNECE-regulation for protective helmets [6]. Thus the head acceleration, *G*, of the helmeted head, i.e. helmeted head form, should not exceed 275*g*. In the meeting with Nolan it was recommended that the total mass of the helmet should not exceed 2 kg (see section 4.4.1). A medium size head form weight 4,7 kg [6], so the total mass of helmet and head form is then 6,7 kg. The maximum force on the helmeted head form is calculated by Newton's second law:

$$F_{\max} = m_{tot+head}G \qquad (7)$$

Then the force on the head form shall not exceed 18 kN at impact.

The free variables are the choice of material and the density of it. The mass of each part should be minimized and for the shell and protective padding an equation for this objective can be set-up:

$$m_s = V_s(A_s, t_s) \cdot \rho_s \qquad (8)$$

$$m_{pp} = V_{pp}(A_{pp}, t_{pp}) \cdot \rho_{pp} \qquad (9)$$

Where V_s and V_{pp} is the volume of each part, which depends on the surface area of the part and the thickness. Surface area and thickness are predetermined by the shape of the helmet and therefore not considered free variables.

4.7.1 Dimensioning the protective padding

The complexity of helmet material selection and dimensioning has led to an experimental approach within the industry. The downside of using experimental testing is high costs and lately computational methods for dimensioning and material comparison have been developed. Due to high costs of experimental testing a simplified design methodology, formulated by Shuaeib et al. [17] will be used for comparing different materials and densities. The method is referred to as energy method A and is based on the padding's ability to absorb impact energy.

4.7.1.1 Material comparison

Energy method A will be used to compare different materials. Mills has developed a simplified mathematical model for calculating the forces transmitted by the foam [12][17]. The model is based on the following assumptions:

i. The part of the helmet where the impact occurs is spherical;
ii. The object hit is a flat, rigid body since the most common object hit is a flat road surface;
iii. The helmet shell has negligible stiffness and does not participate in energy absorption;
iv. The yield stress is constant over the contact area between helmet and the impact object.

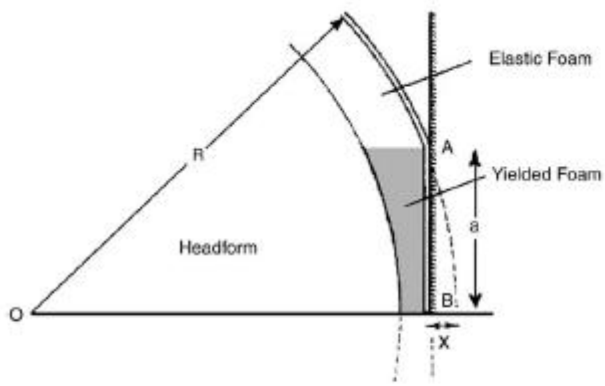

Figure 22 *Geometry for helmet contact area*

Under the assumption of i and ii the geometry between helmet and object hit is given by Figure 22. The first assumption, i, allows the contact area to be regarded as a circle with radius a. As long as the crushing distance of the foam x is much smaller than the radius R of the curvation of the helmet the contact area between helmet and the flat surface is given by:

$$A = 2\pi Rx \quad (10)$$

Because of assumption iv the force transmitted by the foam is given by:

$$F = A\sigma_y = 2\pi Rx\sigma_y \quad (11)$$

(11) is valid as long as the strain is increasing. To be able to compare the effectiveness of different foams using (11) the design point (maximum force, allowed deflection of the foam) has to be determined based on the constraints from testing criteria and the

maximum helmet weight. Assumption ii makes it possible to apply the constraints from the impact-absorption test since the impact is against a flat, rigid steel anvil. By (7) the maximum impact force on the head has been calculated to be 18 kN. The impact energy can be calculated by:

$$E = \frac{mv^2}{2} \tag{12}$$

The impact velocity is 7,5 m/s, hence the impact energy will be approximately 190 J. The impact energy must be absorbed without crossing the injury level of 275*g* or the deflection limit of the foam see Figure 23.

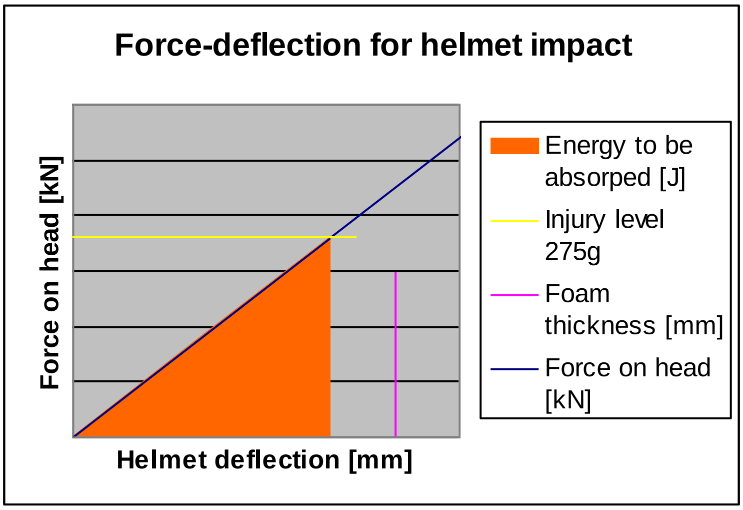

Figure 23 *The input energy that has to be absorbed, not crossing the limits of maximum force on the head and foam deflection*

The relationship between input energy, maximum force and the foam deflection equal to the stopping distance of the striker is given by:

$$E = \frac{F \cdot x_{min}}{2} \tag{13}$$

The foam cannot be allowed to be compressed above its energy absorbing capacity, since this will cause it to bottom out, and the load on the head will increase dramatically. The foam can be compressed to 90% of its total thickness before bottoming out. Inserting values for F and E gives a value for x_{min} of 21 mm and the nominal foam thickness is then approximately 25 mm (which is 90% of the total foam thickness). The design point against which the different foams will be evaluated is therefore established to 18kN and 25 mm deflection.

Foam type	EPS 68	EPS 54	EPS 44	PE 60	PU 50
Density [kg/m^3]	68	54	44	60	50
Yield stress σ_y [MN/m^2]	1.08	0.7	0.46	0.65	0.35

Table 7 *Material characteristics of different foams.*

Three different foams (expanded polystyrene EPS, polyethylene PE and polyurethane PU) were compared. Foam of four different material characteristics, as stated in Table 7, was compared by plotting the impact force against foam deflection using (12). The radius of curvation usually ranges between 170 mm at the side and 100 mm at the front of the helmet, in this case R chosen to be 100 mm. Figure 24 shows the force-deflection curve of the foams.

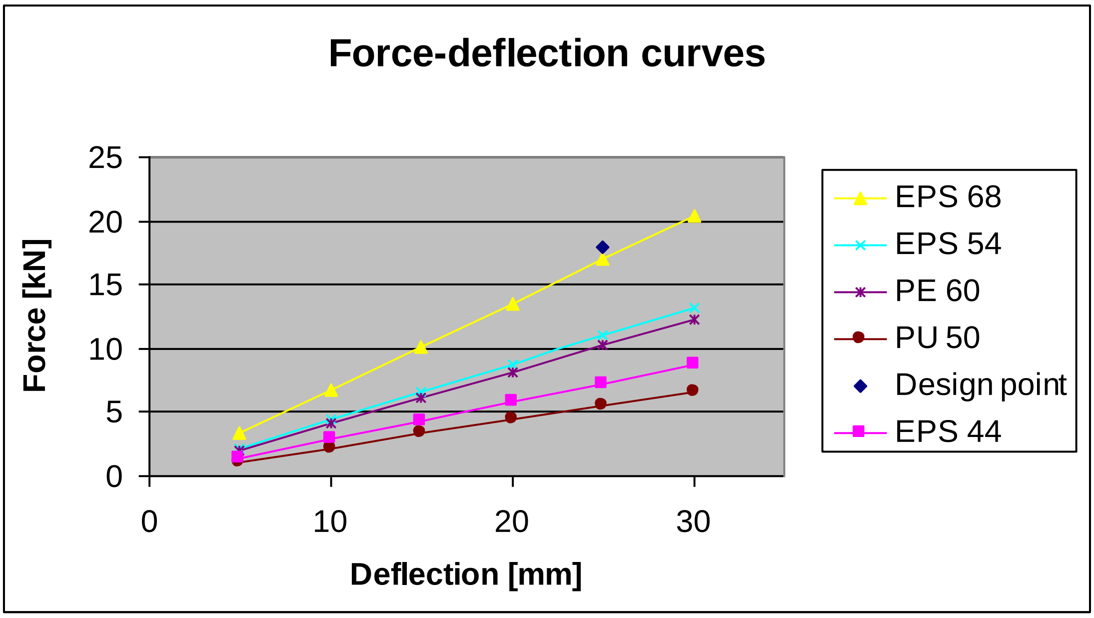

Figure 24 *Force plotted against helmet deflection for foam of different characteristics.*

Since EPS with density of 68 kg/m^3 reaches closest to the design point it will have the ability to absorb the impact energy. Figure 24 also show that EPS of lower density (44 kg/m3) perform better in absorbing loads than PU of higher density (50 kg/m3). The above analysis does not determine the specific density of the foam, but it proves the superior energy absorption abilities of the EPS foam.

4.7.1.2 Density investigation

The protective abilities of the padding highly depend upon the density of the EPS foam. There are three different characteristics of EPS foam that depends on the density. As mentioned in previous section the foam has to be able to absorb a certain amount of impact-energy, the ability to absorb energy increases linearly with foam density. But for a specific energy level the load transferred from foam to head will also increase with density. For a specific energy level there is also a least foam thickness which enables the foam to absorb the amount of energy. Should the thickness be less loads will increase rapidly and the foam is said to bottom out [18]. Since the foam thickness is decided by the shape of the helmet, the density of the foam has to be adjusted to that thickness so that the energy absorption requirements can be met. As can be seen in Figure 25, because of the shape of the helmet shell the foam thickness is not uniform. Also the shape of the helmet will make certain parts of the helmet stiffer than others. The double convexity of the shell at the helmet crow will allow the shell to absorb 30-40% of the impact energy and foam with significantly lower density can be used in this area. On the other hand the edges around the visor will be weaker and in need of higher density foam. Because of the added modules at the top (for the camera and GPS) and at the back (for storage and USB-hub) theses parts will be even stiffer.

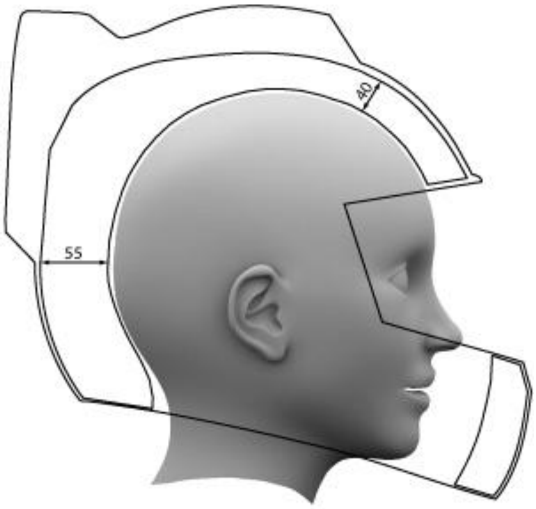

Figure 25 *An example of how the foam thickness varies because of the helmet shape.*

4.7.1.3 Multiple density concept

Because of the variation in foam thickness and stillness of the outer shell the selection of foam density will result in a multi density concept to make sure the safety requirements will be met both regarding ability to absorb impact energy and head acceleration level. The protective padding could be divided in three different areas according to Figure 26. In area 1 low-density foam should be used, since the stiffness of the outer structure and the thickness of the foam will make sure the energy amount can be absorbed; also because of the foam thickness density should not be too high since the foam will then be too stiff and cause high level of head acceleration. Since padding thickness in general is slightly thinner and the outer structure does not offer as much support the foam in area 2 should be of medium density. Area 3 requires medium to high density foam because of the weakness at the edges surrounding the visor and the thin padding in this area.

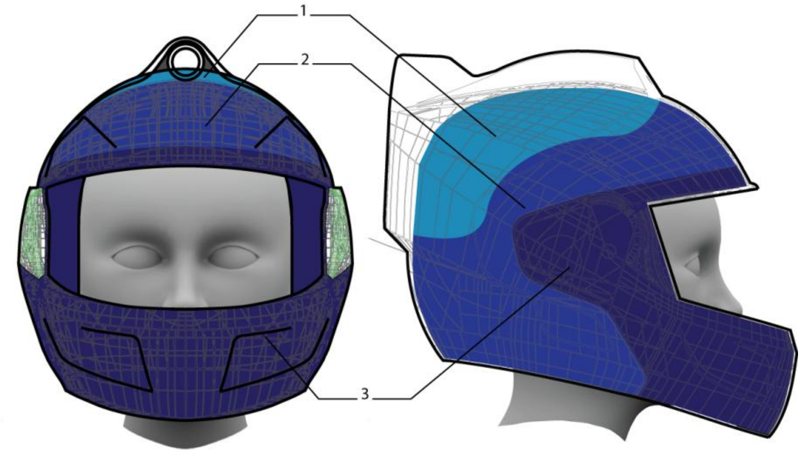

Figure 26 *The protective padding divided into the different density areas.*

4.7.2 Material selection for the helmet shell

Three aspects are important when considering the choice of helmet shell material:

- Protective abilities, (see 1-6 section 2.1.1);
- Weight;
- Manufacturing methods and costs;

Commonly, the materials used in motorcycle helmet shells are; polycarbonate (PC), ABS plastic and fibre reinforced plastics (FRP), strengthened with either glass- or carbon fibre.

All the above materials are used in helmet manufacturing and can provide the necessary protective capabilities. CFRP and GFRP helmet shells are stiffer than ABS and PC shells. Experimental tests of caps from ABS and GRP shells, performed by Mills[12], show that shell stiffness is the double or more for GRP. FRP shell is also generally thinner than PC and ABS shells. However plastic shells have lower density than FRP shells and are therefore generally lighter.

In the case of the prototype helmet GFRP or CFRP are considered to be the reasonable choice for helmet shell material. This choice is primarily based on the small batch size; for the prototype one or very few helmet shells will be manufactured. To manufacture helmet shell parts hand lay-up of resin and woven or knitted carbon fibre can be used.

4.7.3 Design optimization

Using the concept of multiple density foam for the protective padding will allow for a reduction of the helmet's total mass compared to using homogeneous density foam padding. The typical foam thickness ranges between 20-30 mm and varies between different parts of the helmet. For the MoveOn-helmet foam thickness ranges between 40-60 mm and the component modules add further weight to the helmet, therefore a multiple foam concept would be necessary to make sure that helmet weight will not exceed the limit of 2 kg. The concept, shown in Figure 26, consists of three areas with different foam densities. The areas are defined having low, medium and high density foam, with density ranges according to Table 8. A comparison between homogeneous density padding and the multiple-density concept will show approximately how much the mass of the foam padding can be reduced by using the later.

Area	Density	Density range [kg/m^3]
1	Low	20-30
2	Medium	30-50
3	High	50-70

Table 8 *Definition of foam density areas.*

By analysing CAD-data it was estimated that 20% of the protective padding consisted of the low density foam, 40% of the medium and high density foam respectively.

Uniform density foam padding usually has a density of about 50 kg/m^3. As a reference a helmet with foam density of 56 kg/m^3 will be used. If a multiple density concept is used, equation (9) should be modified:

$$m_{pp} = V_{pp}(A_{pp}, t_{pp}) \cdot \rho_{pp} = aV_{pp} \cdot \rho_{pp1} + bV_{pp} \cdot \rho_{pp2} + cV_{pp} \cdot \rho_{pp3} = \\ = (a \cdot \rho_{pp1} + b \cdot \rho_{pp2} + c \cdot \rho_{pp3})V_{pp} \quad (14)$$

Where a, b and c are the percent factor of the helmet volume for each different foam density. Using equation (9) and (14) the foam mass ratio, between a uniform and a multiple density foam concept can be calculated by:

$$R = \frac{(a \cdot \rho_{pp1} + b \cdot \rho_{pp2} + c \cdot \rho_{pp3})V_{pp}}{V_{pp} \cdot \rho_{pp}} = \frac{(a \cdot \rho_{pp1} + b \cdot \rho_{pp2} + c \cdot \rho_{pp3})}{\rho_{pp}} \quad (15)$$

If the densities for foam area 1, 2 and 3 of the multiple-density concept are chosen in the middle of each density interval in Table 8 equation (15) gives:

$$R = \frac{(0{,}2 \cdot 25 + 0{,}4 \cdot 40 + 0{,}4 \cdot 60)}{56} = 0{,}8$$

This example shows that by using the multiple-density concept the mass of the protective padding can be reduced by 20% and a weight reduction would be necessary to obey mass limitation of 2 kg.

5 Summary

5.1 The helmet concept

The final concept consists of a helmet shaped to store the requested devices. Because of the innovative modifications of the helmet, in comparison to conventional helmets, a multiple density concept is suggested to be used for the protective padding. A multiple density foam concept would make sure the helmet mass does not exceed the limitation of 2 kg. A presentation of the concept is shown in Figure 27. The camera is installed in a module in the top of the helmet. The suggested outer shell material is carbon fiber reinforced plastic.

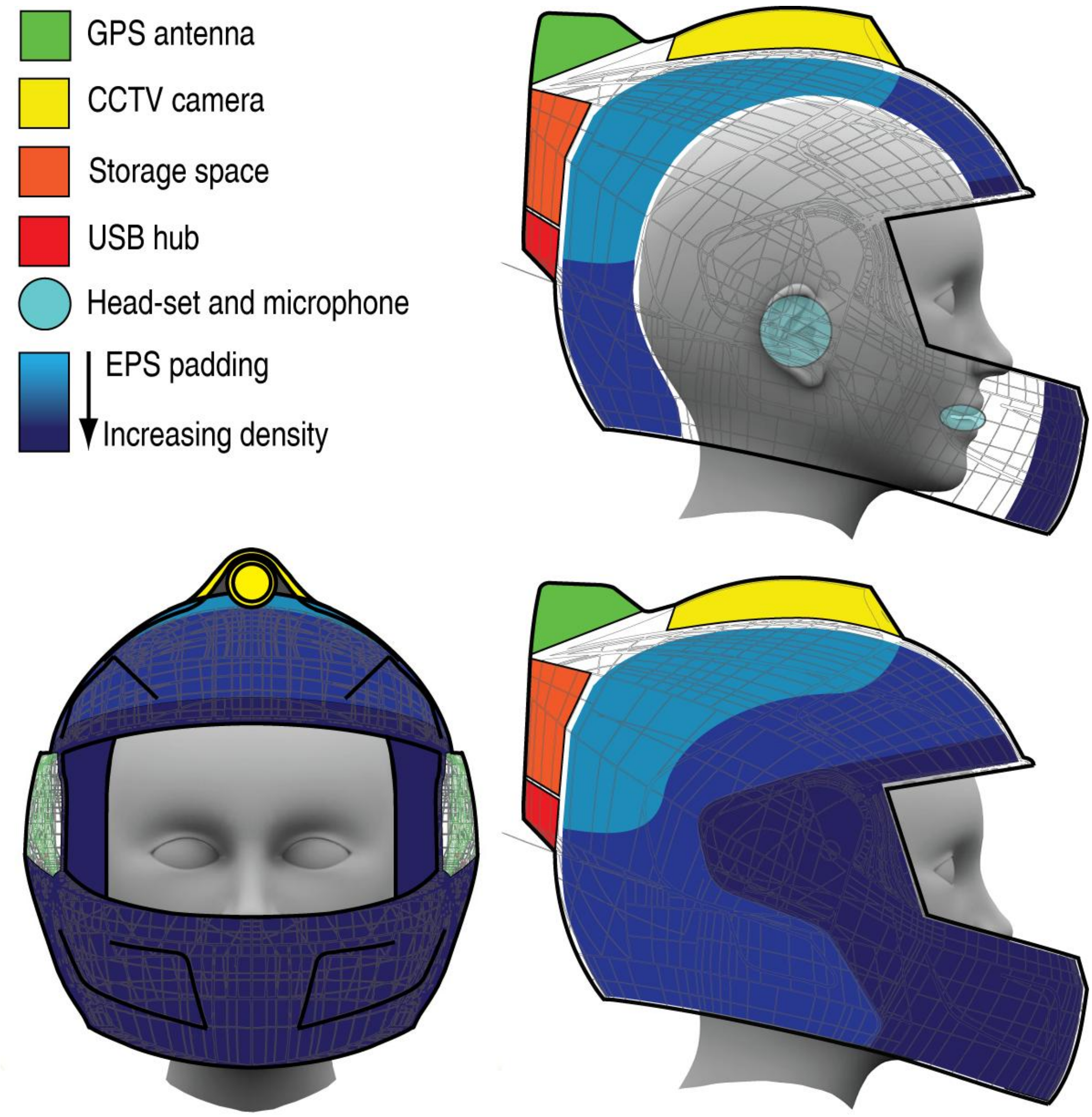

Figure 27 *The helmet and protective padding concept.*

6 Conclusions

When designing a new helmet concept the aspects of safety, comfort and usability, aero-acoustics and manufacturing are important. Countries within the European Union have agreed to follow the United Nations regulation for protective helmets [6] and new helmet design has to undergo these testing procedures too before being introduced to the European market. A helmet gets the safety approval if it passes a number of experimental tests, including crash testing and testing of field of view among others. Experimental testing is both time-consuming and expensive and therefore research has been done to develop a numeric method for impact-absorption testing. There are examples of attempts to use both finite element methods (FEM) [2] and mechanical mass-spring-damper systems [19] for modelling helmets. But more comparative studies between experimental and numerical testing must be done before computer analysis can be used to evaluate the safety of a new helmet concept. Here a multiple-density concept has been suggested for the protective padding. It has been shown that the concept would reduce the mass of the helmet compared to a uniform density concept which in this case is necessary to keep helmet weight below the maximum limit of 2 kg. Furthermore impact-absorption tests based on FEM models have shown that a multiple-density protective padding could reduce head accelerations and improve safety compared to conventional designs [2]. By using a simple method for comparing different foams EPS has been concluded to have the best abilities for impact-absorption purposes. However, EPS-foam padding in general and multiple-density foam in particular is complicated and expensive to manufacture [20]. The costs of manufacturing a single prototype helmet including multiple-density foam would be costly since both safety testing of the new concept and manufacturing would be expensive. Therefore it is suggested that a prototype to be used only to test the integrated communications system is developed. Guidelines and suggestions for such as prototype are as follows:

- The prototype can be based on a helmet already tested and safety approved for the market;
- The camera module and storage space in the back of the helmet can be handmade of FRP and then mounted onto the helmet used as a base for the prototype;
- The camera can be installed as recommended in chapter 4.6 and according to appendix H;
- Microphones and earphones can be installed on the inside of the helmet perhaps with minor adjustments of the comfort and protective padding.

Such a prototype would allow the MoveOn communication system to be tested using economical manufacturing methods for the prototype. However, this prototype does put restraints on the testing procedures. Since the outer shape of the helmet is modified without any safety testing, it is suggested that the test is performed at low speed and on a restricted area should there be any on bike testing. Since the components of the system are simply added to the helmet the weight of the helmet will increase and test interval should be short enough to not tire the test person. Since high speed testing most probably cannot be performed because of safety reasons, CFD analysis could be valuable for evaluating aero dynamics and aero acoustics.

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A. Function analysis

Company: Pininfarina

Project: MoveOn

Specification: Helmet concept (and system)

Basic functions

Function		**Classific-ation***	**Note**
protect	head against impact	MF	according to standard
Allow	communication	N	
offer	pictures	D	
offer	indications	D	
minimize	noise	N	
Allow	to remain in-com	D	with helmet removed
Allow	localisation	N	of position
offer	wire-less system	D	
Allow	one-hand control	N	
offer	voice-command	N	
not impair	with field of vision	N	
Have	good aerodynamics	D	
provide	adequate cover	N	
Be	reliable	N	
resist	water	N	
be	comfortable	N	
express	security	D	
express	authority	D	
minimize	weight	N	
resist	dirt	N	
Allow	operating while on move	D	
offer	electrical power	D	to power devices

* MF=main function, N=necessary, D=desired, U=unnecessary

Ergonomic functions

Function		**Classific-ation**	**Note**
reduce	noise	N	
minimize	weight	N	
minimize	stress on neck	N	
maximize	freedom	D	
offer	different sizes	N	
minimize	stress on shoulders	N	
Allow	ventilation	D	

not impair	with field of vision	N	
protect	against sunlight	D	
provide	adequate cover	N	
Be	unobtrusive	N	
protect	against draft	N	

Safety functions

Function		Classific-ation	Note
protect	head against impact	HF	according to standard
protect	face against scratch	N	
Keep	helmet in position	N	in case of fall
not impair	with vision	N	
protect	against sunlight	D	
provide	adequate cover	N	
offer	sizes	N	according to standard
Be	unobtrusive	N	
resist	water	N	
provide	safe fit	N	
reduce	noise	N	

Design functions

Function		Classific-ation	Note
minimize	weight	N	
absorb	impact forces	N	
distribute	forces	N	shell
protect	face	N	shell
Allow	sliding against surfaces	N	shell
support	structure	N	shell
prevent	fracturing of inner foams	N	shell
protect	as large area as possible	N	protective padding
offer	stopping distance to head	N	protective padding
offer	stiffening of structure	N	protective padding
offer	appropriate fit	N	comfort padding
fulfil	requirements of impact absorption test	N	ECE-R22-Rev4 standard
fulfil	requirements of projection and surface tests	N	ECE-R22-Rev4 standard
fulfil	retention system test	N	ECE-R22-Rev4 standard

Prototype functions

Function		**Classific-ation**	**Note**
minimize	costs	D	
Allow	use of standard components	D	
offer	evaluation of speech-command system	D	
Allow	aero-acoustic evaluation	N	
allow	aero-dynamic evaluation	N	
Be	durable	N	

B. Components characteristics

Table 9 shows the relevant devices dimensions to be considered.

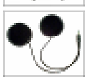
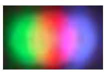
Device		Dimensions		
		w (mm)	h (mm)	d (mm)
Camera		50	50	50
Microphone	  	7,5	15	7,5
Earpiece		15	63	15
LED:s	 	30	20	20
GPS-antenna		50	20	50
Additional space		70	50	50
USB-hub		35	20	35

Table 9 *Dimensions of devices to be integrated in the helmet*

C. Placement of components

Figure 28Figure 32 shows the possible placements of the devices to be integrated into the helmet, also listed above.

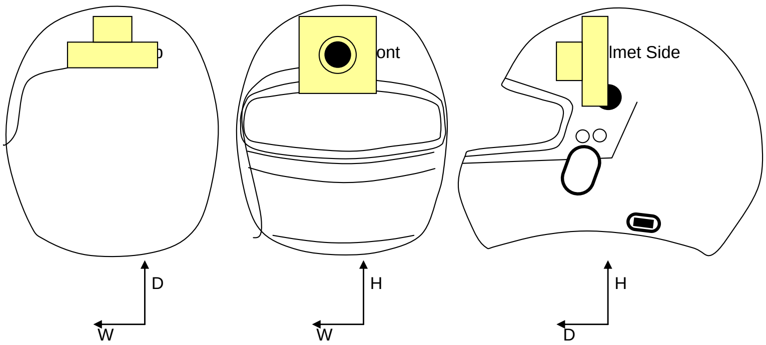


Figure 28 *Placement of helmet camera*

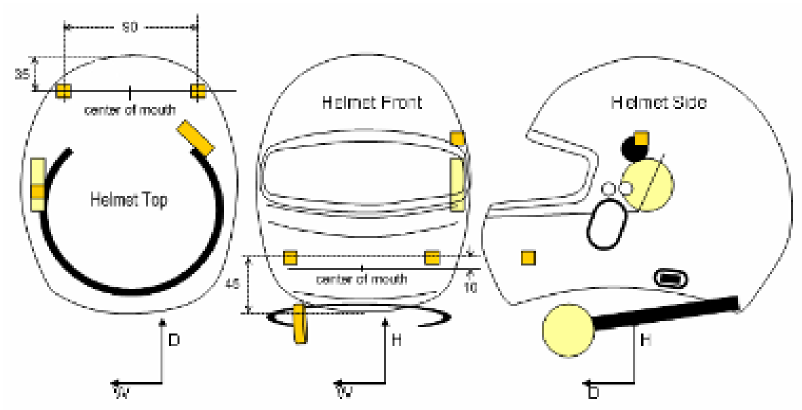


Figure 29 *Placement of microphones and earpieces*

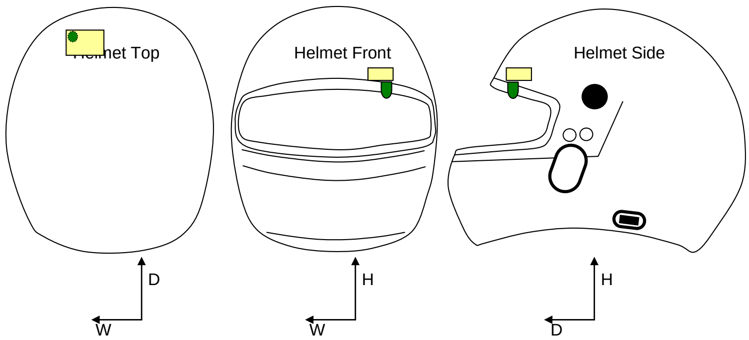


Figure 30 *Placement of HUD*

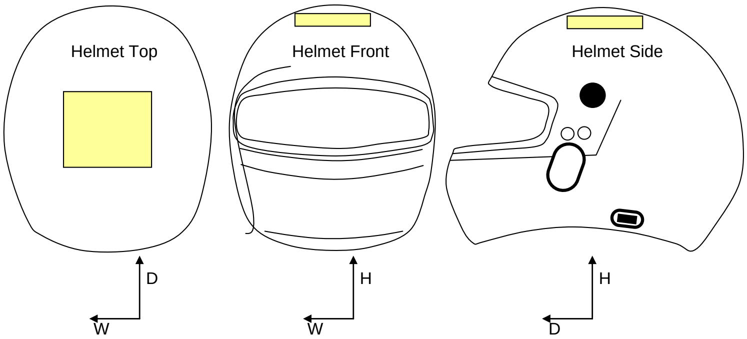


Figure 31 *Placement of GPS-antenna*

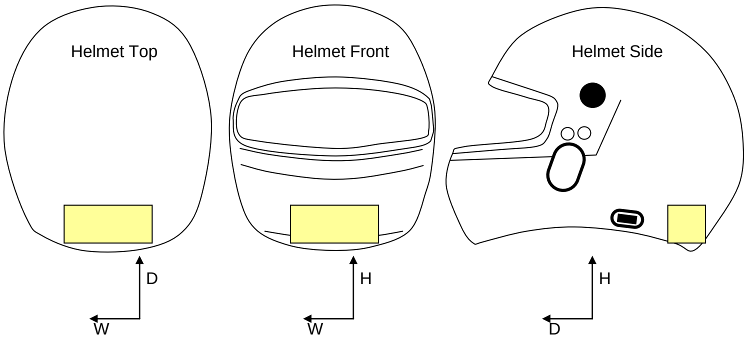
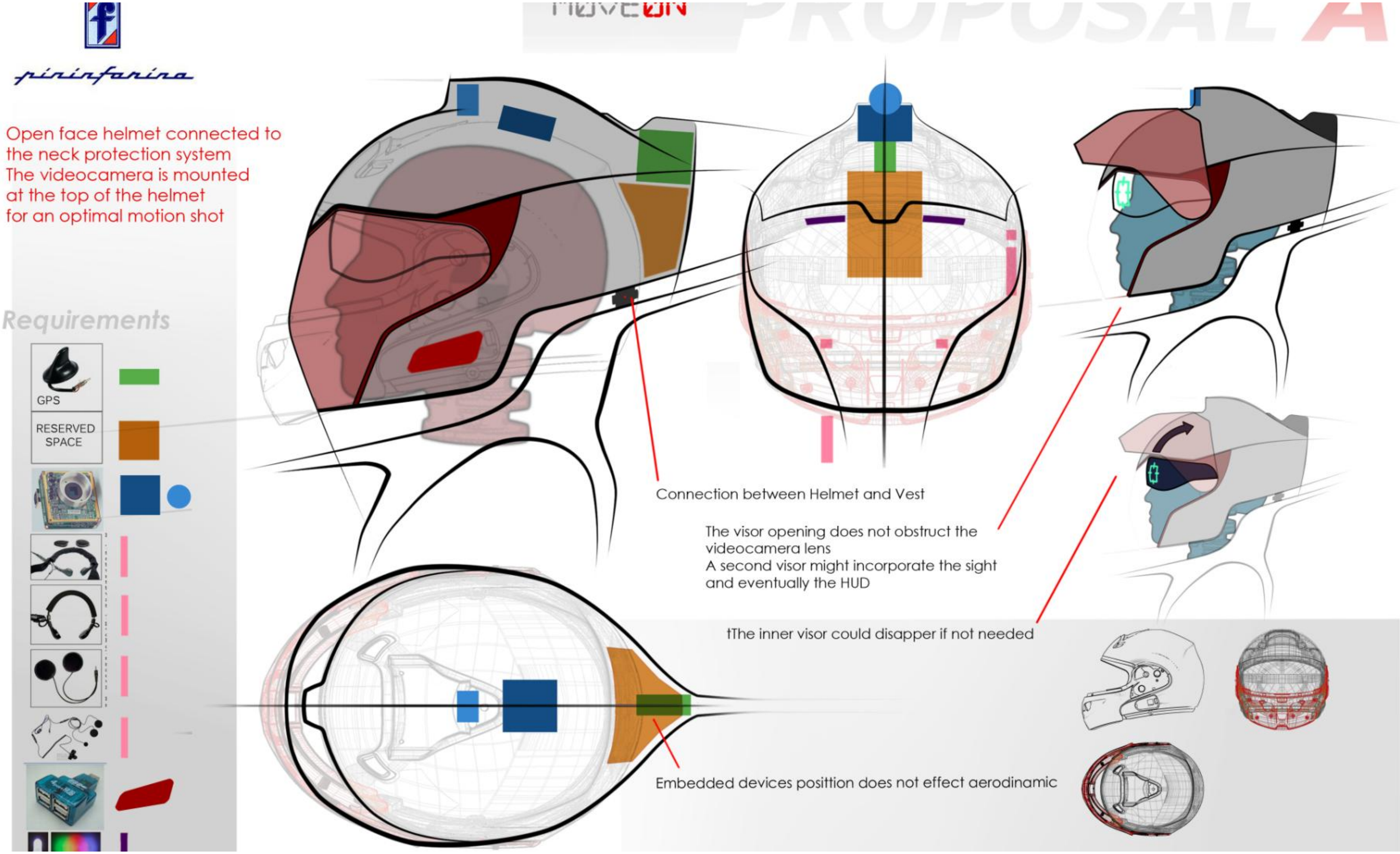


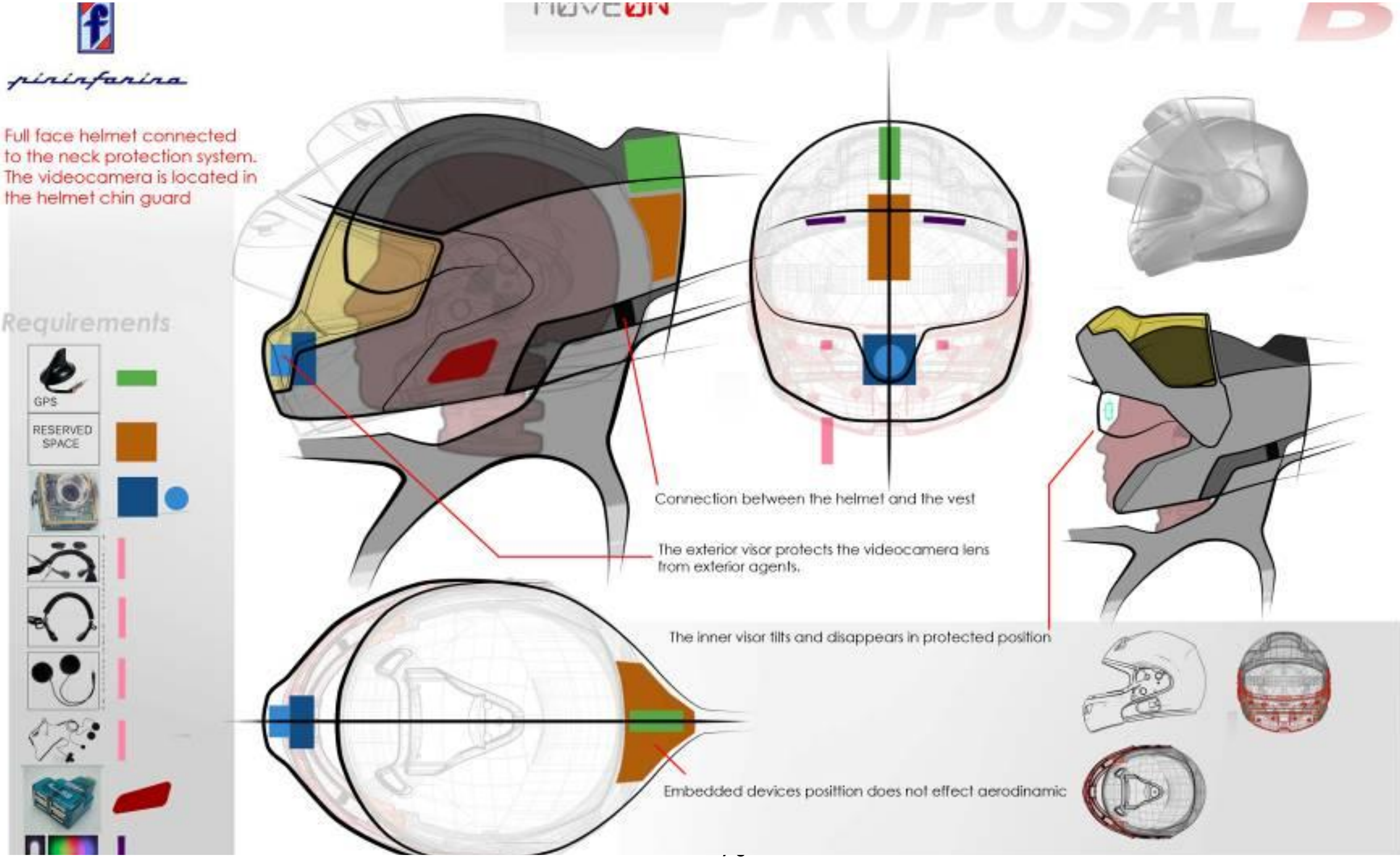
Figure 32 *Placement of additional space*

D. Concept A



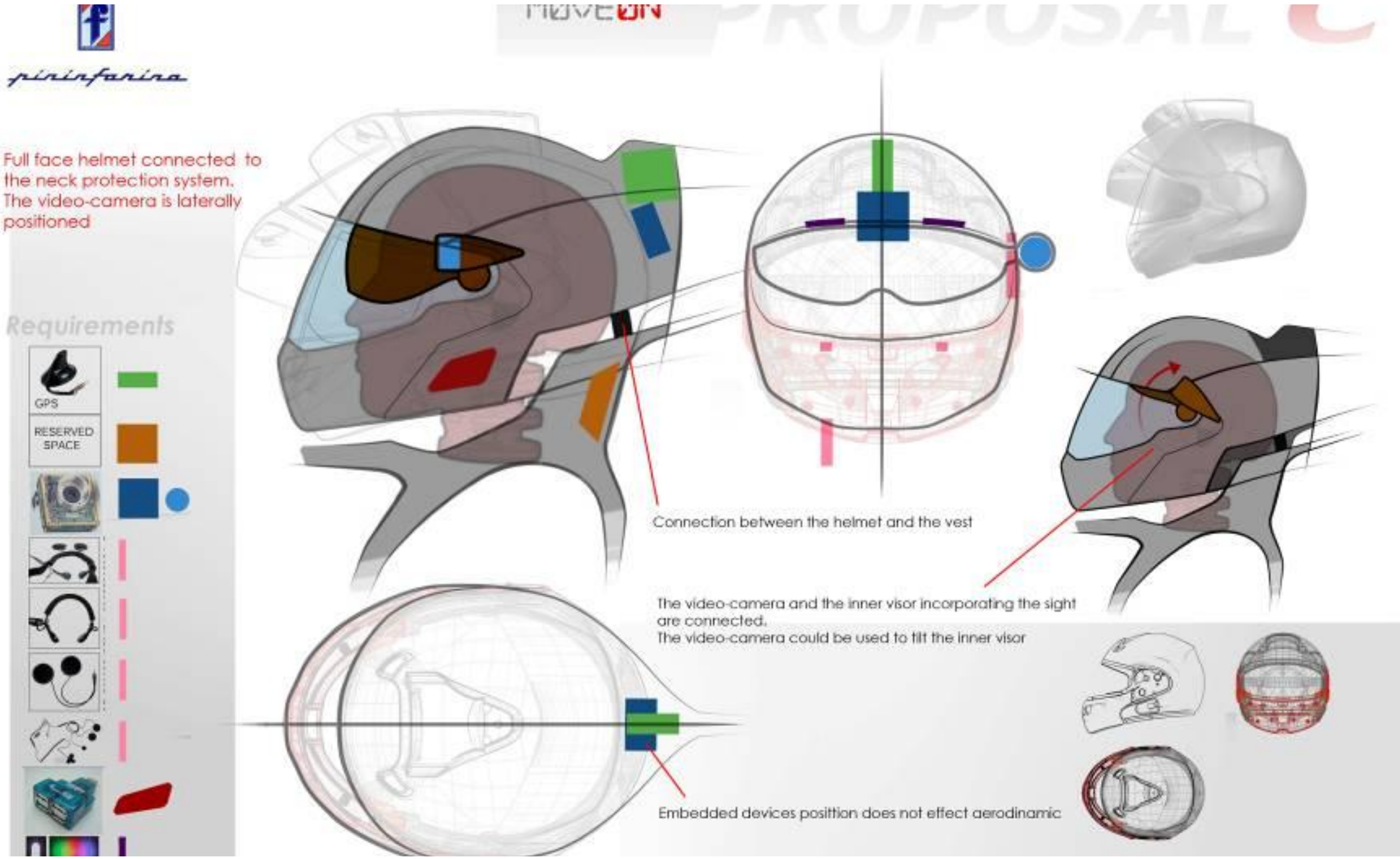
MOVE ON
PROPOSAL A
pininfarina
Open face helmet connected to
the neck protection system
The videocamera is mounted
at the top of the helmet
for an optimal motion shot
Requirements
GPS
RESERVED SPACE
Connection between Helmet and Vest
The visor opening does not obstruct the
videocamera lens
A second visor might incorporate the sight
and eventually the HUD
tThe inner visor could disapper if not needed
Embedded devices posittion does not effect aerodinamic

E. Concept B



pininfarina
Full face helmet connected
to the neck protection system.
The videocamera is located in
the helmet chin guard
Requirements
GPS
RESERVED
SPACE
Connection between the helmet and the vest
The exterior visor protects the videocamera lens
from exterior agents.
The inner visor tilts and disappears in protected position
Embedded devices posittion does not effect aerodinamic

F. Concept C



pininfarina
MOVE ON
PROPOSAL C
Full face helmet connected to the neck protection system. The video-camera is laterally positioned
Requirements
GPS
RESERVED SPACE
Connection between the helmet and the vest
The video-camera and the inner visor incorporating the sight are connected.
The video-camera could be used to tilt the inner visor
Embedded devices posittion does not effect aerodinamic

G. Pugh matrix

CONCEPT EVALUATION				
MoveOn 1. Full face helmet, flip up front, camera on top 2. Full face helmet, flip up front, camera on side 3. Open face helmet, visor and chin hoop, camera on top				
	Weight factor	1	2	3
Protect head against impact	5	+1	+1	0
Good aero acoustics, low noise	5	+1	+1	-1
Good aero dynamics	4	0	0	0
Visibility	4	0	0	+1
Low weight	4	-1	-1	+1
Face cover	4	+1	+1	-1
Water/dirt resistance	4	+1	+1	-1
Comfortability	4	0	0	+1
Low stress on neck/shoulder	4	-1	-1	+1
Openable front face	4	0	0	+1
Integration of microphones	4	+1	+1	-1
Integration of camera	4	+1	0	+1
Integration of LED	3	0	0	0
Integration of HUD	3	0	0	0
Integration of GPS	4	+1	+1	+1
Storing battery	3	-1	-1	+1
Wireless communication	4	+1	+1	-1
One-hand control	4	0	0	0
Voice command control	4	+1	+1	-1
In-com with helmet removed	3	-1	-1	-1
Prototype realization	4	0	0	0
Standard manufacturing	2	-1	-1	-1
Innovative	4	+1	0	0
Number of +		10	8	8
Number of -		5	5	8
Sum		5	3	0
Weighted sum		26	18	1

Table 1 *Evaluation matrix for the three concepts*

H. Helmet module: Design and dimensions