Safety Analysis of Autonomous Emergency Braking (AEB) System

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ABSTRACT
Driver assistance systems (DAS) and active safety systems have for some time been active topics of research and development. One of the developments in active safety systems is Autonomous Emergency Braking (AEB) systems which can provide collision warning and emergency braking. Several automakers have already commercialized AEB systems in their products and many others are performing different types of reach to find information on AEB and advanced and difference features. These systems are made to eliminate the chances of crashes and increase vehicle overall emergency safety. Till now a lot of hard work has resulted various information on collision mitigation and avoidance technology papers have been discovered and published, were as only a few has been on collision avoidance and mitigation systems which are same as the thinking and most important and difficult process of human life i.e. decision-making like human and learning different driving characteristics of the many human driver on a roadway. This paper introduces the AEB system and studies about various hazard scenarios associated with AEB system, fault-tree analysis of the hazards and proposes the mitigation factors which could reduce the effect of risk or probability of crashes. Also, this paper proposes some techniques which can be used to reduce the risk factor associated with AEB.

INDEX TERMS:
Autonomous Emergency Braking, Automatic Braking System, Collision avoidance, AEB.

1. INTRODUCTION
Autonomous emergency braking (AEB) systems distinguish an approaching forward crash with another vehicle so as to dodge or reduce the crash. This safety system first caution the driver recover move to evade the crash. On the off chance that the drivers reaction isn't effective to stop the the crash, the Autonomous emergency braking may consequently using the braking system to help with forestalling or lessening the seriousness of an accident. The NHSTA trusts these advances speak to the following flood critical advances in vehicle wellbeing. AEB systems, for example, dynamic brake support (DBS) and crash imminent braking (CIB), have the capability not only to save life of the diver but other as well who are involved in an accident [1].

1.1 TYPES OF AEB
Autonomous emergency braking are accessible in 3 types: High Speed, City Speed and Pedestrian AEB. Every producer has an alternate name to it. Yet the highlights are basically same and utilize comparative innovation. Every vehicle only have one of these AEB systems or a mix,

High Speed or highway Speed AEB can recognize your vehicle closing the gap with another vehicle in front of you up to 100-150 meters away and start the alarm as well as reduces speeds and starts slowing process. This occurs at parkway speeds utilizing Range-go radar.

Low Speed or city drive AEB may utilize light lasers to identify a car ahead and all the more rapidly use the brake in an unpredictable rush hour gridlock circumstance where the alert system.

Pedestrian detection emergency braking utilizes imaging devices to distinguish nearness of people or creatures on close to the roadside. A caution & programmed stopping might be included. This is the most current innovation and less much of the time found, however soon ought to be very common.[1]

![Figure 1 Process working of AEB](Image)

2. HISTORY
The main present day forward impact evasion system was shown in 1995 a group of researchers and designers in Malibu, California, at Hughes Research Laboratories. It was financed by Delco Electronics, and was driven by HRL physicist Ross D. Olney. The innovation was showcased as Forewarn. Its a radar based system - an innovation that was
prominently accessible at Hughes Electronics, yet not financially somewhere else. A little exceptionally created radar receiving wire was created particularly for this car application at 77 GHz. In August 1997, the principal generation laser versatile journey control on a Toyota vehicle was presented on the Celsior model (Japan as it were) [2].

In the mid 2000s, the U.S. highway administration examined whether to make frontal impact cautioning systems and lane takeoff cautioning systems mandatory. In 2011, the European Commission explored the incitement of "crash moderation by braking" systems. Mandatory fitting (additional cost alternative) of Advanced Emergency Braking Systems in business vehicles was booked to be actualized on 1 November, 2013 for new vehicle writes and on 1 November, 2015 for every single new vehicle in the European Union. As indicated by the "effect assessment", this could avert around 5,000 fatalities and 50,000 genuine injuries for each year over the EU.[1]

Example of what some car manufacturers call AEB

- **Alfa Romeo:** Autonomous Emergency Braking
- **Audi:** Pre Sense Plus
- **BMW:** Driving Assistant Plus
- **Ford:** Active City Stop
- **Holden:** Automatic Emergency Braking City Stop
- **Honda:** Collision Mitigation Braking System
- **Hyundai:** Autonomous Emergency Braking
- **Kia:** Autonomous Emergency Braking
- **Land Rover:** Autonomous Emergency Braking
- **Lexus:** Pre-collision Safety System with Brake Assist
- **Volvo:** City Safety

3. WORKING AND COMPONENTS

The speed range over which an AEB system works is reliant on the type and complexity of sensors used. Improved performance can be accomplished by joining different sensor types together in 'combination' to supplement each other for example camera and radar together. Seventy five percent of all impacts happen at speeds under 20mph in purported 'City' driving situations. This is the place AEB systems utilizing the cost proficient lidar sensor are extremely compelling, normally keeping away from crashes at speeds up to 12-15 mph and moderating those up to 25mph. Significant accidents incorporate those that happen at intersections roundabouts and in stop begin low speed activity ordinarily with one auto running into the back of another. More mind boggling, yet costly radar sensors expand on the low speed ability with the possibility to maintain a strategic distance from impacts with stationary and moving vehicles crosswise over at higher rates. Joining radar and camera sensors in "combination" offers the possibility to likewise address passerby and other helpless street client crashes. The camera supplements the radar's going capacity by empowering object discovery and arrangement thus adds to the general execution abilities of these systems. AEB detecting advancements are growing quickly empowering a regularly expanding capacity to keep away from crashes [3].

AEB is blend of different components used in a vehicle with different types of safety level. As AEB is a sensor fusion through which the car's autonomous system works. It utilizes different distinctive kinds of sensors including laser, high frequency radar and Camera as an extra sensor source.

![Figure 2 Sensor fusion in volvo](image)

Sensor data fusion consolidates the advantages of various sensors and estimating standards in the best way that is available, along these lines giving information that individual sensors working freely can't create. Data fusion of numerous sensors increases the measurement reliability, range and accuracy. The diverse estimating standards are additionally used to affirm recognized items.

3.1. LASER SENSOR

A laser sensor works in light of the triangulation distance measurement principle. Triangulation or geodesy is a technique used to quantify distances with the assistance of triangles. The laser beam, that is not the same as the customary light in its high beam arrangement, is transmitted by a radiator to the surface of a deliberate question. Any deliberate surface, even that comprising of infinitesimal inconsistencies, would then mirror the laser beam, and send it back to the sensor's recipient regardless of the question's aura in space. The special case here would be the mirror surfaces of items, where as indicated by the law of light reflection, the beam would return at the indistinguishable edge, which would imply that the reflected flag would then not be gotten by the sensor's recipient. The occurrence edge of the laser beam changes relying upon the separation to the question, which thus adjusts the situation of the beam dab on the recipient made of a line of photodiodes. The information from the beneficiary are perused utilizing a unique small scale controller,
though the controller figures the edge of light dispersion on the photodiode line, and decides the separation to the question in view of these information. The utilization of controllers guarantees high linearity and exactness of estimations. The sensor consequently changes with various hues that are likewise recognized by the smaller scale controller. Laser sensors are viewed as a standout amongst the most famous arrangements that are exceedingly requested for in the present market. Not at all like numerous other nearness sensors, these gadgets perform exceptionally exact estimations that are independent of the range and are described by consistent esteem.

3.1.1. TIME OF FLIGHT

Modulated beam system uses the light that travels for and back from the source to target. But the time is not only calculated by the light travelled. But also by the strength of the light beam. As the strength of the laser beam reduces after some time. As delay in time is calculated by comparing the laser signal with the same late signal returning from the final object to source. Best example for such is "phase measurement" in which it forms a sinusoidal curve equation and reflected light is compared by the phase of the signal going out.

One of the biggest limitation of phase measurement is accuracy in the freq of modulation and its ability to solve the phase difference among the signals. To overcome these limitation in phase measurement system some modulated new, rangefinders works on a frequency conversion principle. In these upgraded system, laser light is modified and reflected from target is collected wit the help of lens and is focused onto photodiode which is placed inside the instrument. With the upgraded system the results of the system’s recovered and recreated up to the required level and then inverted. Afterwards it is used to modulate the laser diode. The laser is emitted and collimated using the front face of the sensor. Because of these kind of formations creates an oscillator effect, with the laser and changes state form on to off using its own signal.

To determine at time of oscillation, to figure out the time at which the laser is changes state from on to off is actually similar to the time taken by the laser to go and reflect back from the target along with the time needed for its amplification.

Beam sensors are mostly applied in Middle spectrum range applications, for calculating and finding distances as maximums as 10 feet to as small as few inches. With the help of reflector this Ange can be extended more than hundreds of feet.

3.2 CAMERA SENSOR

Camera-based collision avoidance braking systems depend on the joining of a few vehicular segments working in conjunction with each other amid a short field of time. To begin with, the front aligned cameras identify autos and different questions in front of the auto inside the system’s noticeable range. The processing system of the auto utilizes a calculation to decide the relative rate of conclusion (how quick the auto is moving toward the question contrasted with the protest’s speed) and chooses whether or not to caution the driver. In the event that the driver does not back off or brake, the vehicle cautions them with either a light, a notice on the show, or a sound. The expected aftereffect of this notice is to alarm the driver so as to stay away from the crash, yet on account of driver nonresponse, the vehicle takes more precaution measures. The camera system and processing system at that point train the programmed braking system to respond. It either starts to moderate the vehicle or conveys it to an entire stop in view of the computed separation and time before the looming impact. Through the utilization of these precaution measures, a crash can be completely maintained a strategic distance from or diminished in force.

The camera systems could reduce or eliminate accidents involving pedestrians or animals significantly by detecting the threat, notifying the driver, and braking if necessary. Camera systems are being used for rear-view detection in larger vehicles such as SUV’s recently as well. It aids by giving the driver visibility in what would normally be the blind spots in their view, and thus preventing more possible accidents with unseen objects. These rear-facing cameras are also useful for people with neck problems and the elderly, whose mobility and swiftness of reaction may not be as quick as some other individuals’ reactions.[6]

Figure 4 Working of Camera sensor using AI

3.3 RADAR SENSOR

Radar is another one of the major sensor that helps the cars to locate other objects in various weather conditions such as rainfall and dense smog or fog. Because radar can scan and pass through obstacles, such as shrubs and grass. The environment advantage of the radar the radar adds to the vision.
of the driver as it can help to view wider and more area around the vehicle compared to one direction by human
driver. This results can help the driver an heads up inform-
ation regarding the object.

Figure 5 Combination of radar with Mercedes grill

The Major technology after it contents of various FMCW radar having different shapes and sizes antenna patterns. Nowadays, available in the markets are can find and evaluate signals which are transmitted earlier or even an consider echo signals. from other surrounding objects in additions to the basic system. Often such system are combined with additions
sensors such as camera for images and lasers.

Maximum number of cars are equipped with 3 major
types of radars either 2.4e+7 kHz i.e. (24 GHz) , 7.6e+7 KHz
or 9.6e+7 kHz (W band). According to the use of radar either
frequency range i.e. FMCW radar is used or (For any long
distance) a FMICW radar is used. These High frequency
transmitter are basically antennas arrayed with different feed-
ing points. As each feeding points results in different antenna
patterns with main beam direction. To switch between the
feeding points a PIN diode is used. because of the process the
antenna patterns can change very quickly. (ie electronically
scanned), so that it can scan 2 dimensions objects in the di-
rection of travel.[5]

3.4. LIDAR SENSOR

The working behind LIDAR is every simple. Its just cal-
culating the amount of time taken by light to go and come
back from a reflected piece of mental. Example the light that
comes back on the eyes retina when a object is shines because
of light reflected from it when using a torch.

As we all know light travels very fast 300,000 kilometres
per 1 sec , nearly 186000/sec or approximately 0.3m/ 10 ^-9
sec which seems to be instantaneous. Thats why Lidar are
used to be operated so fast. Because of so much development
in the technology this is possible.

The calculation for measuring distance of the protons
travelled form the source and to came back of source is sim-
ple:

\[ D = \frac{S \times T}{2} \]

\[ D = \text{Distance} \]

\[ S = \text{Speed of light} \]

\[ T = \text{Time of flight.} \]

The LIDAR device basically shoots rapid lazer light dots
to the surface of the object sometimes 150,000 pulses per sec-
ond. And the receiver calculates the time taken by various
pulses to bounce back of the surface. As light moves at con-
stant speed i.e. speed of light so because of this the system
becomes highly accurate to calculate the distance between
them. By doing this repeatedly the system makes a complex
'maps' of reflected pulses of the surface of the object. With the
help LiDAR other data is equally important to collect with
maximum accuracy. Sensor changes its positions dramati-
cally such as its vertical heights, gyro orientation and also its
gars location. So the instrument should consider the light
send and received can be 2 different positions. any kind of
information is very important for data's security. For surfaced
fixed LiDAR we can label them on GPS location.

Generally there are 2 different kind of LIDAR detection
methods. Incoherent which is also called as Direct energy
detection, and to find ou Coherent. Coherent systems are it
strong to measure phase sensitive measurements and mostly
used for optical heterodyne detection along with that they are
quite good to calculate doppler effect. This helps the system
to work on much lower power but adds some drawbacks such
as it becomes more complex and expensive. In different types
of LIDAR has two major pulses : micro pulse and high - en-
ergy system.

MicroPulse system is actually the result of more power-
ful and greater computational capabilities. where the lazers
are low power consuming allowing them to be used in safety
instruments.

Whereas Higher energy system are more often used in
atmospheric and pressure related studies where they are used
for calculating atmospheric parameters such as height, tem-
perature, trace gas concentration, humidity, cloud particles
properties and layering & density of clouds.[3]

Figure 6 Dot projections of LIDAR Sensor
4. HAZARD SCENARIOS FOR THE SYSTEM

![Risk and hazard Analysis Table](Figure 8)

A hazard is an operator which can possibly make hurt a powerless target. Hazards can occur at any time at any point. There are a lot of hazards associated with the automation in cars and their emerging trends. This paper focuses on the hazards related to Autonomous Braking System in cars. Some of the common hazards could be:

1. Reckless Driving: Due to reckless driving, sometimes the tactical decisions which the controller of the car should take are not in line with the weather conditions, environment or the road rules. Due to which, the chances of a car crash increases.

2. Sensor Failure: Automation in cars and vehicles is all about sensors, their reliability and control. If the sensors are not reliable or they are not working properly, there are high chances that the car would lead to a crash.

3. AI respond time failure: Artificial Intelligence plays a major role in automatic braking system in cars. What if the AI does not respond in time or what if the AI fails to detect an obstacle in your path and respond to it at required times.

4. Traffic Rules: Traffic Rules could be a cause for hazard too. It would be a hazardous situation as well.

5. Weather Conditions: The reliability of sensors is of utmost importance in AEB. The hazard lies in the answer that how will the sensors react at the times of unfavourable weather, whether they will be able to respond appropriately or not.

6. Car conditions: Other conditions of the car also come into play like the braking capabilities of the car, the steering smoothness etc.

5. FAULT TREE ANALYSIS

On the basis of various risks and hazards associated with Autonomous Emergency Braking System, this paper focuses on the fault-tree which has been made by considering all the hazards and the risks on road. The figure below shows the fault tree analysis for an AEB system.

![Fault tree analysis for AEB](Figure 7)

This analysis method is mainly used in Automatic Emergency Braking System to study the safety engineering and reliability of all the components of the system. The fault-tree analysis being done in this research helps in understanding how this system can fail, which component can fail and to identify the hazards with highest risk so as by reducing the risk associated with those hazards can actually make this system safer. [9]

Based on the results of Fault-tree, some of the hazards have been identified as the ones with highest risk factor which needs to be reduced.

Out of all, hazards like False alerts, pedestrian detection failure and sensor failure have the highest risk amongst all the possible hazards. The risk level associated with these hazards is too high and is not acceptable. So, the scope of this paper is to study about these three hazards in particular and suggest some productive measures to reduce the risk level associated with these three types of hazards. [7]

For the hazards with medium and low risk level, there are some inherent safety solutions suggested in the table above, which can further lower the level of risks currency associated with these.

6. LAYERS OF PROTECTION ANALYSIS (INHERENT SAFETY)

Layer of Protection Analysis (LOPA) is a hazard management strategy usually utilized in chemical industry that can give a more explanatory, semi-quantitative analysis of the dangers and layers of security related with risk situations. LOPA permits the security analyzing group a chance to find shortcomings and qualities in the wellbeing frameworks utilized to ensure representatives, the plant, and the general population. LOPA is a way to distinguish the situations that present the most critical hazard and decide whether the results could be lessened by the utilization of inherently more secure safety standards. LOPA can likewise be utilized to recognize the requirement for safety instrumented systems (SIS) or other assurance layers to enhance process safety.

Adding layers of safety measures or inherent safety features in the components of the car can reduce the risk by a large extent. [8]

This paper focuses on three different protection layers which can be added to the car design to make it more safe and reduce the probability of risks. They are:

Layer 1: Alert System
Layer 2: Partial Action
Layer 3: Emergency System

6.1. ALERT SYSTEM

Alert system is the insurance system for a car if the driver does not react on time. On the off chance that the system
distinguishes an obstruction in the way and faculties the driver isn’t responding, it initiates a capable of being heard crash cautioning signal and a makes an impression on the driver's show educating the driver of the high danger of impact. Furthermore, an extraordinary brake-help framework is initiated which builds brake-pedal affect ability, conceivably helping the driver to maintain a strategic distance from an impact.

6.2. PARTIAL ACTION

This layer of protection responds in case there is no action against the situation by the driver given by alert system. if in case there is now reaction by the driver. The system goes into other state of alert where it gives clear signal to the driver and tries to alert the driver so that they can take control of the vehicle. Even incase the driver still does not response back another even clearer signal to the driver by applying the service brake gently, reducing speed of the vehicle and illuminating the brake lights. This part only used particle or small amount of brakes of the vehicle. only to reduce the speed of the vehicle. The system undertakes such action only when the distance to the obstacle has roughly halved since the original warning system.

So the partial Action applies on small amount of brakes to that will braking in case of emergency the car should not cause a rear collision as the driver a driving his car behind the car may not be aware of the situation. So due to this layer a chain reaction of accidents are stopped.

Figure 9. Protection layer diagram and time calculation

6.3. EMERGENCY SYSTEM

Final Layer of the system consist of the most important system as emergency braking if the person does not responds even after previous layer as incase of Fatal accident to driver the car can apply automatic brakes of the car and save the driver from a serious front-collision.[12]

7. CALCULATION

Autonomous Emergency Braking works on knowledge of a Gradient Environment. For better idea, the framework execution of an ordinary AEB framework is improved by calculating the impact of slopes on vehicle’s actual breaking capacity. Past reports, the TX chance file is characterized as the proportion of separation and speed, as appeared in Equation (1).

The Autonomous Emergency Braking is worked by using the stopping agent of vehicle against the forward force i.e. brakes when the hazard list TX is lesser than a specific esteem. The braking time figured of a traditional Autonomous Emergency Braking system is enhanced with an Autonomous Emergency Braking calculation which thinks about impacts of driving on a grade. Similarly the braking time in an ordinary investigations, this examination utilizes an Autonomous Emergency Braking system introduced on one of the test vehicle Volvo. For this the test vehicles, full brakes are used only in case TX ≤ 0.9 s [12].

\[ TX = \frac{\text{Vehicle speed}}{\text{Braking rate}} \] (1)

Along this proposition, the braking time changes by thinking about street inclination, as opposed to ascertained utilizing a replacement time, for example, 0.9 s. Fig 1 gives a chart to the delayed Autonomous Emergency Braking framework thinking about an inclination. The proposed AEB framework uses 100% braking only increase \( TX \leq \frac{\text{Vehicle speed}}{\text{Braking rate}} \), by looking at TX impact hazard list and another hazard record that thinks about an angle, \( \frac{\text{Vehicle speed}}{\text{Braking rate}} \). Eq. (2) offers the condition for computing \( \frac{\text{Vehicle speed}}{\text{Braking rate}} \). In this condition, \( \frac{\text{Vehicle speed}}{\text{Braking rate}} \) is the base deceleration separate, ascertained by Eq. (3). To figure the base deceleration remove, the most extreme deceleration \( \frac{\text{Vehicle speed}}{\text{Braking rate}} \) is ascertained. Accepting a head moving vehicle is reduces its acceleration at a consistent rate, the most extreme deceleration is figured utilizing Equation  . (4). So this condition, while ascertaining a most extreme deceleration \( \frac{\text{Vehicle speed}}{\text{Braking rate}} \), an angle for the driving condition is mulled over, and \( \mu \) is the street surface grinding factor, thought to be 1. At the point when a vehicle is running, if Equation (5) is fulfilled, a crash is stayed away from by using 100% of the brakes of the car and also discharging the throttle at the same time.

\[ \text{TX} = \frac{\text{Vehicle speed}}{\text{Braking rate}} \] (2)

\[ \frac{\text{Vehicle speed}}{\text{Braking rate}} = \frac{\text{Vehicle speed}}{\text{Braking rate}} + 1.2 \] (3)

\[ \frac{\text{Vehicle speed}}{\text{Braking rate}} = -\frac{\text{Vehicle speed}}{\text{Braking rate}} \left(\frac{\mu}{1 + \frac{\text{Vehicle speed}}{\text{Braking rate}}}\right) \] (4)
8. SCOPE OF THE PAPER

Having just the inherent safety features and increasing the reliability of the sensors not all what’s needed. The automation in cars is a huge trend but it needs some foolproof because it has got many lives associated with it.

According to a recent news in The New York Times dated March 19, 2018, a driverless uber vehicle with all the safety features installed in it was on a testing phase across the streets of Arizona where it hits a lady crossing the road. The lady was hit so badly and the impact of accident was so big that the lady died on the spot.[11]

This technology has to be foolproof because it is directly associated with the human lives. Therefore, going beyond the scope of the paper, this research paper is suggesting some more protective features that could further reduce the risk to a large extent. Some of the proposed features are:

1. Introduction of Corona effect into the car system: Corona effect is the conversion of red scale image into the gray scale image in which any source of light will appear as a black spot in the midst of the grey scale image. Corona segmentation can be used particularly for nighttime brake light system. Due to the Corona effect, even a very small source of light can be highly visible and distinguishable.

2. Use of Sensor- Fusion: Usage of a large number of sensor fusions rather than using a dedicated sensor for each and every component can help in mitigating theorists and their impacts. The combination of night-vision sensor and thermal sensors can be highly useful. During the night-time, the thermal sensor can sense any obstacle by sensing the temperature of that obstacle which then can combine its results with the night-vision camera and can help in increasing night visibility for the automatic cars and their braking systems.

3. Use of a number of moderate sensors rather than relying on one very expensive sensor.: Rather than relying on just one or two really extensible high reliability level sensors, it would be better to use a combination of a large number of moderately expensive sensors. This is because if one sensor fails, the other could respond so as the third, fourth and so on.

4. Use of dedicated 360 degree LIDAR: At least one 360 degree LIDAR should be used in every car to capture the 360 degree view. This will help the AI to keep a track of all the obstacles that might come even from the sides of the cars and not just the front.

5. Use of processed big data for the computation by AI rather than using raw data: The computational time for AI would be very less if it were supplied with processed data instead of raw data. Using processed big data analytics the computation time can be reduced.

9. RISK REDUCTION FACTORS

The tables below shows the results of the analysis done with and without proposed safety measures.

Therefore, by using the inherent safety measures and the use of proposed safety measures the likelihood of risk has been reduced to a large extent. The Probability of failure on Demand(PFD) was 0.01 in case of pedestrian Detection which has been changed to 0.0001 after the safety features. Also the PFD for false alerts has been changed from 0.01 to
0.001 whereas the PFD for Sensor failure has been changed from 0.001 to 0.0001.

Figure 13

10. CONCLUSION

The present paper investigates all the hazard and risk scenarios associated with Autonomous Emergency Braking System. This research paper then uses all the hazard scenarios to do a fault-tree analysis for the AEB System. It then calculates the risks involved in all the hazards and tries to mitigate the risks and reduce their impact. Also, this paper suggests some inherent safety measures that can be used to increase the reliability of the system. Apart from that, this paper suggests some measures that can be implemented to the AEB technology to reduce the level of risks involved in the highly occurring hazard scenarios. Simulation and experimental proof have been given which shows the possibility of the resulted idea, and additionally the way that a switch handles framework can be the proper decision in the thought about this content. However, the constraints of the accessible test set-up, and its disparities as far as a real vehicle let the need of testing on a sample model open. Additionally, various essential perspectives still should be investigated: the control framework power versus the quality of the sensors; the coupling of a dynamic framework that like that used for safety frameworks or dynamic frameworks as of now available, similar to ABS or ESP; some other problems in regards to the user and the passenger of a car furnished with the programmed pre-crash impact evasion framework here introduced, and also the sort of driving a. These could be the future extent of work on this theme. REFERENCES