Designing a Rapid Deployment Emergency Services (RapiDES) Vehicle for 2020:

Addressing the problem of ever increasing traffic delaying the emergency services vehicles in big cities

by

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ABSTRACT

This thesis/project is about the design process of designing a conceptual vehicle design that responds to a growing global phenomenon of ever increasing traffic congestion delaying emergency response times of various emergency services. This thesis aims at establishing the case for a smarter, smaller and more responsive emergency services vehicle design by first looking at the phenomenon of ever increasing traffic volume in big cities around the world particularly in North America, examining the causes and consequences of traffic congestion, and identifying the most critical impact it causes which is on the emergency response times of various emergency services which makes a difference between life and death with a minute's delay to the scene.

The thesis then attempts to offer a solution with the accompanying practical project focusing on designing a Rapid Deployment Emergency Services (RapiDES) vehicle for the near future (2020) to meet the challenges of saving lives and properties in a quick and responsive way. This design of RapiDES will serve as a baseline model for the North American context and can be modified to suit the needs and requirements for other markets. The design requirements and key features of RapiDES are generated and described in the Design Brief of RapiDES as a result of rigorous research mapping exercise and scenario studies of RapiDES in action for the three emergency services of EMS, fire rescue and law enforcement.

The core essence of the thesis is the novel proposition that existing emergency services vehicles are too large and are themselves part of the problem of delay in response times. Thus it is imperative for a new vehicle design for the emergency services that is narrow and streamlined in order to weave through heavy traffic easily in order to reduce the response time and to reach the scene of emergency safe and dry with the required equipments.

The outcome of the design is represented by a scaled model, full-sized side view rendering, and several renderings of RapiDES performing tasks in environments as described in scenario studies and design brief. These artefacts serve as a means of evaluating the design as is commonly practiced in automotive industry in the initial stage of a vehicle design project. The design fulfils the requirements entailed in the design brief and is deemed successful of passing the initial stage of a real vehicle design project.

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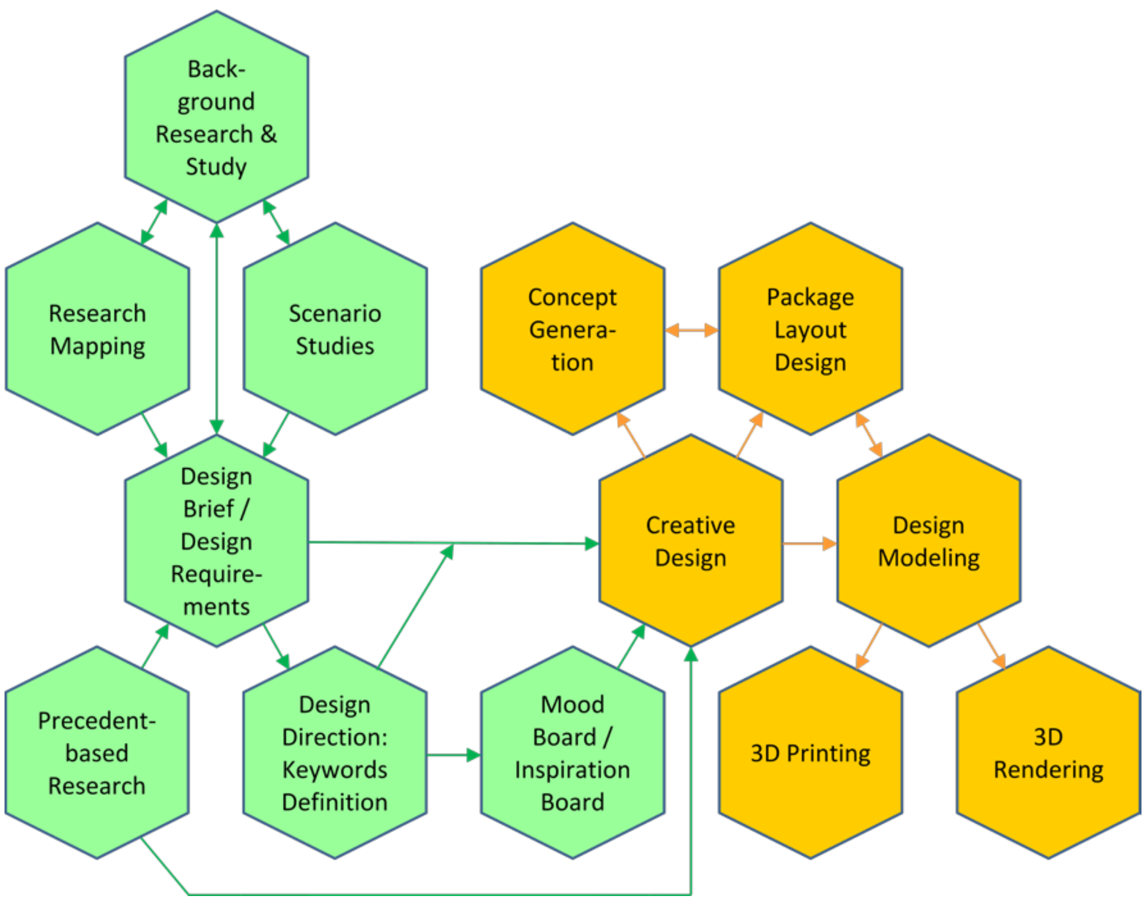
TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

This thesis/project is about the design process of designing a conceptual vehicle design that responds to a growing global phenomenon of ever increasing traffic congestion delaying emergency response times of various emergency services. The design and development of the concept of Rapid Deployment Emergency Services (RapiDES) vehicle is done in the stages of background research and study, research mapping, scenario studies, design brief / design requirements, precedent-based research, concept exploration, package layout design, design modeling, scaled physical modeling with the help of 3D printing and rapid prototyping, and 3D rendering. As illustrated in Figure 1.1, this design process is iterative, and sometimes chaotic in nature. Some of the stages are not done in linear path, but rather bouncing back and forth between them.

Figure 1.1. RapiDES design process.



The outcome of the project will become a baseline design of RapiDES for the North American context which can be customized for the three emergency services to handle various emergency situations. This baseline design can then be modified to suit the needs and contexts for other parts of the world. The outcome of the design is represented by the 3D printed scaled model and various 3D renderings, as full size working prototype is not financially or technically feasible. The scaled model and renderings also serve as the only means of evaluating the success of the design.

In the stage of background research and study, the phenomenon of traffic congestion, its causes and consequences are being examined. Among these consequences, the most critical issue of traffic congestion is identified as the impact on emergency response time which may impact the safety of lives and properties.

From this background research and study, it is found that while many potential solutions to reduce emergency response time have been suggested, none of these suggestions have addressed one of the root problems, which is the fact that the size of conventional emergency services vehicles such as the jumbo-sized ambulances and the mammoth-sized fire engines, is part of the problem itself.

Therefore, it is imperative for a solution to address these issues for the emergency services to reduce the response time and to reach the scene of emergency safe and dry with the required equipments. This thesis aims at establishing the case for a smaller, smarter and more responsive emergency services vehicle design, and then attempts to offer a solution with the accompanying practical project focusing on designing a RapiDES vehicle for the near future, which is in the year of 2020, to meet these challenges and requirements.

In order to better understand the complicated issues surrounding the problem of traffic congestion delaying the response time of emergency services, a research mapping exercise is carried out which helps us to illustrate the big picture of the interwoven factors. Then, scenario studies will also be done for the three emergency services of emergency medical services, fire department, and police department, to simulate the various emergency scenarios these services will be facing in the near future. These scenario studies provide valuable insights to the demands and requirements of these services in order to perform their challenging tasks.

As a result of the mapping exercise and scenario studies, the key features and requirements for the design of RapiDES become clearer and more convincing. The Design Brief of RapiDES (Appendix A) is generated based on these exercises. One of the most important requirements for RapiDES is to have a narrow frontal profile in order to be streamlined enough to filter through heavy traffic with ease. The need for a narrow-bodied vehicle results in the selection of single track (in-line) two-wheel configuration like a motorcycle. The need to protect the crews from the elements results in the fully enclosed vehicle. However, a fully enclosed motorcycle-like vehicle will have problem in balancing in low speed and stationary because the operator cannot support the vehicle with his/her feet. The resultant of all these requirements yields a fully enclosed in-line two-wheel vehicle stabilized with gyros.

In precedent-based research stage, the brief history and current development of gyro-stabilized vehicle designs will be reviewed. Gyro-stabilized vehicles have long existed since the early days of motor vehicle history. In fact, all of the previous gyro-stabilized vehicles have failed to develop beyond prototyping stage. The exact reason for this is still unknown but could be attributed to people's lack of confidence in something that seems to be unstable in nature. Therefore it would better to pilot the implementation of such vehicles with the uniformed units such as the emergency services discussed here, because they are better trained and are more receptive in accommodating new technologies in their job. As the pilot project becomes successful with various emergency services, the general public will have higher levels of confidence and acceptance in these cool-looking, environment-friendly, space saving and energy efficient vehicles.

The creative design stage of designing RapiDES takes place mainly after all these groundwork are laid, even though some early sketches of the design were done without much research. Through the scaled 3D printed model and concept renderings of RapiDES operating in the contexts as outlined in scenario studies and design brief, the success of the design will be evaluated. The design of RapiDES should be served as a catalyst for the development of such vehicles in the next five years, possibly with a corporate partner, that will be beneficial to the well-being of humankind.

It should be emphasised that even though some technical aspects of vehicle design and gyro-dynamics will be mentioned in this thesis/project, the focus is on the industrial design aspect of vehicle design.

In the next chapter, the background research and study stage will start by looking at the causes and consequences of traffic congestion and the most critical impact of this will be identified.

CHAPTER 2: CHARACTERIZING THE DESIGN PROBLEM

In this chapter, the causes and consequences of traffic congestion in big cities particularly in the North America will be examined and analyzed. The most critical impact of traffic congestion is being identified as the delay in emergency response times which have direct impact on the safety of lives and properties of people. The effects of the quickness of emergency response times of various emergency services will be reviewed to confirm the importance of quick emergency response time in saving lives and properties of people. Then the effectiveness of some proposals to reduce emergency response times by some authors will be scrutinized.

2.1 Traffic Congestion: Causes and Consequences

In recent years traffic volumes have increased tremendously around the world. By 2009, more than half of the households in the United States own two or more vehicles.[1] In 2010, the number of vehicles on the roads worldwide surpassed the 1 billion-unit mark for the first time ever.[2] The staggering average growth of 3% per year since 1964 is roughly double the growth rate of world population over the same period of time.[3] This rapid growth rate of vehicle and hence traffic volume is largely caused by urban sprawl, modern parenting, and improved spending power in some emerging markets.

Urban sprawl is a phenomenal development pattern in the United States and Canada characterized by low density building, poor roadway networks, and residential zoning that separates from commercial districts.[4] These characteristics have caused negative

[1] Adella Santos et al. *Summary of Travel Trends: 2009 National Household Travel Survey.* Trends of Travel Behaviour, Washington DC: US Department of Transportation, 2011.

[2] Sousanis, John. "World Vehicle Population Tops 1 Billion Units." *WardsAuto.* August 15, 2011. http://wardsauto.com/ar/world_vehicle_population_110815 (accessed May 23, 2015).

[3] Paul Gao et al. "A road map to the future for the auto industry." *McKinsey Quarterly*, 2014: 42-53.

[4] Howard Frumkin et al. *Urban sprawl and public health: designing, planning, and building for healthy communities.* Washington DC: Island Press, 2004.

consequences of longer travel distance, increased traffic congestion, and higher rate of traffic and pedestrian fatalities.[5]

The stress and demands of modern parenting in North America has been attributed to one of the causes of traffic congestion.[6] When both parents enter the work force, there will simply be more people on the roads. Furthermore, the errands usually done by the other parent at home are now done by either parent commuting between workplace and home, dropping on and off children at daycare or soccer class. These additional errands cause the predicted commuting time 18 minutes longer (excluding the time stopped) than those commuters who do not have to stop for errands.[7]

Over the past decade, China's rapid economic growth has fuelled the growth of vehicle sales nationwide. In 2009, China overtook the U.S. to become the world's biggest automobile market with a total of 13.8 million cars and trucks sold in that year.[8] Despite the recent slowdown in economic growth, IHS estimates that annual car sales in China will surge to 29.9 million units in 2019.[9]

This increased number of vehicles worldwide has caused traffic congestion especially in big cities and has become a major problem to the well-being of the inhabitants and a threat to the economy. A seminal study conducted by HDR Corp. commissioned by Toronto's Metrolinx on the annual cost of congestion in Greater Toronto-Hamilton area

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[5] Matthew Trowbridge et al. "Urban Sprawl and Delayed Ambulance Arrival in the U.S." *American Journal of Preventive Medicine*, 2009: 428.

[6] Moore, Oliver. "Why traffic congestion is driving Toronto crazy." *The Globe and Mail.* May 3, 2014. http://www.theglobeandmail.com/news/toronto/constant-gridlock/article18406658/?page=all (accessed May 24, 2015).

[7] Turcotte, Martin. *The Time it Takes to Get to Work and Back.* General Social Survey on Time Use: Cycle 19, Ottawa: Social and Aboriginal Statistics Division, Statistics Canada, 2005: 13.

[8] Chen, Xiaojie, and Jinhua Zhao. "Bidding to drive: Car license auction policy in Shanghai." *Transport Policy*, 2013: 39.

[9] IHS. "The forces of change across China are not homogeneous." *IHS.* https://www.ihs.com/industry/automotive/china/ap5.html (accessed 5 24, 2015).

was estimated at $6 billion in 2006[10]. This economic loss as a consequence of traffic congestion was due to the idle time by employees, delay in deliveries, fuel wastage, wear and tear of automobiles, accidents as a result of congestion and increased insurance cost, and decreased patronage in businesses.[11] Another cost that is difficult to estimate is the environmental pollution from the greenhouse gas emissions from idling cars that causes health related problem. In 2007, Toronto Public Health attributed 440 premature deaths and 1700 hospitalizations to air-pollutants caused by traffic.[12]

2.2 Traffic Congestion: Impact on Emergency Response Time

Apart from these problems, the other critical impact of traffic congestion is on emergency response time which has significant impact on patient survival.[13] Griffin and McGwin conducted a survey from November 2009 to February 2010 in the state of Alabama in the U.S. to "assess the impact of roadway design and traffic congestion on EMS response (particularly response time) per the opinions and experiences expressed by EMS providers."[14] The study found that "on average, traffic congestion increased time-to-scene by 2.5 min and time-to-destination (e.g., hospital) by 5.8 min, for a total increase of 8.3 min."[15]

The state of Alabama has relatively lower density of vehicle compared to the other states in the U.S. Based on the statistics of "State Motor-Vehicle Registration – 2003"[16]

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[10] Acharya, Madhavi. "Gridlock: The $6 Billion (at least) problem." *thestar.com: Business.* November 29, 2013. http://www.thestar.com/business/2013/11/29/gridlock_the_6_billion_at_least_problem.html (accessed September 30, 2014).

[11] Ibid.

[12] Ibid.

[13] Griffin, Russel, and Gerald Jr. McGwin. "Emergency Medical Service Providers' Experiences With Traffic Congestion." *The Journal of Emergency Medicine* 44, no. 2 (2013): 398.

[14] Ibid., 399.

[15] Ibid., 402.

[16] Federal Highway Administration. "STATE MOTOR-VEHICLE REGISTRATIONS - 2003." *Federal Highway Administration.* October 2004. http://www.fhwa.dot.gov/policy/ohim/hs03/htm/mv1.htm#foot2 (accessed May 24, 2015).

and the “United States Summary: 2010 Population and Housing Unit Counts”,[17] the density of vehicle by state is formulated in a table in Appendix B: Top 30 Vehicle Density by State in The United States In 2003. Alabama is only ranked the 26th in vehicle density among the 50 states and D.C. Therefore the study done by Griffin and McGwin has bigger implications in other states with higher vehicle density, that is, the delay of 8.3 minutes in emergency response time in Alabama will surely be longer in those states with higher vehicle density than Alabama. While it might not be accurate to assume that the state of New Jersey with more than 10 times the vehicle density of Alabama’s could experience 10 times longer emergency response time, the actuality is certainly not optimistic.

2.3 Effect of Emergency Response Time on Patient Survival

How critical exactly is emergency response time to patient survival, especially those who suffer from sudden cardiac arrest? A research that spans over a period of 12 years by the largest integrated non-profit medical group in the world, the Mayo Clinic in Rochester, Minnesota, has measured the “call-to-shock” time to the second, from the time emergency call is received to the moment a shock is administered with defibrillator to the patient.[18] The research shows that the patients who are saved from ventricular fibrillation received the shock on average within 5 minutes 30 seconds.[19] It also shows that those patients who were not saved received the shock not until, on average, 6 minutes 42 seconds after the emergency call was received.[20] This study shows that speed is so critical to the survival of sudden cardiac arrest patients that even less trained

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[17] United States Census Bureau. *United States Summary: 2010, Population and Housing Unit Counts, 2010 Census of Population and Housing.* Population and Housing Unit Counts, Washington, D.C.: United States Census Bureau, 2012: 41.

[18] Davis, Robert. "The price of just a few seconds lost: People die." *USA Today.* May 20, 2005. http://usatoday30.usatoday.com/news/nation/ems-day2-cover.htm# (accessed June 7, 2015).

[19] Ibid.

[20] Ibid.

first responders who get to the patient with a defibrillator before the arrival of ambulance can make a difference between life and death.[21]

This finding leads to an interesting development of the role of police officers in Rochester, they are no longer law enforcers only but also emergency medical caregivers. Whenever an emergency call involving cardiac arrest victim is received, the emergency dispatcher will broadcast the call over the police radio, alerting the police officers patrolling on the street nearby the scene. These officers are equipped with defibrillators and are able to shock and save the patients before the ambulance arrives. The result is impressive: the Rochester officers have been the first to shock 37 of the 73 cardiac arrest patients that were saved over a period of 12 years.[22]

Note that the research in Rochester focuses on the effect of emergency response time on the survival rate of cardiac arrest patients specifically. How about those patients with medical conditions other than cardiac arrest? Do they stand a chance to survive with faster emergency response time? A separate research done in Denver over the period of one year studied the effect of emergency response time on the survival rate of patients of various severity of illness.[23] It should be noted that the Response Time in this study "was defined as the interval (in minutes) from the initiation of the 911 call to the arrival of the ambulance at the scene."[24] The data collected is presented in a chart as shown in Appendix C: Percentages of Survival to Hospital Discharge by Paramedic Response Time and Stratified by Risk Groups.

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[21] Davis, Robert. "The price of just a few seconds lost: People die." *USA Today*.

[22] Ibid.

[23] Peter Pons et al. "Paramedic Response Time: Does It Affect Patient Survival?" *Academic Emergency Medicine* 12, no. 7 (July 2005): 594.

[24] Ibid., 595.

From the chart, it is evident that response time (to the scene) less or equal to 4 minutes is beneficial to the survival of patients of both high risk and intermediate risk groups. After the 4 minutes cut-off, the survival rate of all patients remains consistent. This finding of 4 minutes response time to the scene critical to the survival of patients also echoes the Rochester's finding of 5 minutes 30 seconds "call-to-shock" time critical to the survival of cardiac arrest patients. Therefore it can be confidently concluded that faster emergency response time, whether it be "call-to-shock" time or "to-the-scene" time, does indeed improve the survival rate of not just cardiac arrest patients, but also patients of other severity of illness.

2.4 Effect of Emergency Response Time on Fire Rescue

Fire growth, which is the rate of spread and the intensity of fire, is directly related to the factor of time. As a general rule, a fire grows to double in size with every minute without aggressive measures of fire suppression.[25] When the fire continues to burn and the temperature of the burning room rises to 1100 to 1200 degree Fahrenheit, flashover may occur.[26] Flashover is defined as the point when "all combustibles in the space have been heated to their ignition temperature and spontaneous combustion occurs."[27]

Flashover is a critical point of fire growth for two reasons. First, beyond flashover point the chances of survival in the burning room are virtually non-existent. Second, beyond flashover point the rate of combustion becomes much higher and requires significantly more water to reduce the burning material below its ignition temperature.[28]

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[25] Mansfield Fire Fighters. "4 Minute Engine Coverage." *Mansfield Fire Fighters.* http://iaff266.com/engine (accessed June 12, 2015).

[26] Ibid.

[27] Arthur Cote et al. *Fire Protection Handbook.* 19th. Quincy: National Fire Protection Association, 2003.

[28] Mansfield Fire Fighters. "Fire Growth and Flashover: The Importance of Rapid Response to Residential Fires." *Mansfield Fire Fighters.* http://iaff266.com/flashover (accessed June 12, 2015).

In the Fire Propagation Curve and Flashover Point as shown in Appendix D, National Fire Protection Association (NFPA) estimates that a residential structure fire will reach the flashover point in about 8 minutes' time.[29] Data generated by NPFA presented in the Table of Fire Extension in Residential Structures, 1994-1998 (Appendix E) shows the relation between fire extension and human and property losses, which is directly governed by the factor of time. That means the longer the fire burns without suppression measures, the more losses it causes. Therefore the ability to respond rapidly and suppress the fire aggressively will greatly affect the outcome of fire rescue mission.

2.5 Effect of Emergency Response Time on Crime Crackdown

How does police response time affect the chances of apprehension of offenders? Coupe and Blake conducted a study in the UK "to examine the extent to which quicker responses by more patrols result in more arrests at and near burglary scenes, and to assess the effects of extra patrol cover on capture at or near the scene."[30] Among the patrol variables they measured were "response times (calculated from call receipt times, patrol departure and arrival times at the scene), and numbers of officers and units attending each sample incident."[31]

The study found that the success of catching burglars in the act at the crime scene or nearby depended very much on how responsive the police can reach the scene and the strength of response, that is, how many patrol units responded to the emergency alert and rushed to the scene.[32] An average of 2.7 patrol units responded to emergency alerts, 61 percent of which were crewed by two officers while 36 percent were single

[29] National Fire Protection Association. *NFPA 1710.* Standard, Quincy, MA: National Fire Protection Association, 2010: 17.

[30] Coupe, Richard Timothy, and Laurence Blake. "The effects of patrol workloads and response strength on arrests at burglary emergencies." *Journal of Criminal Justice* 333, no. 3 (2005): 239.

[31] Ibid., 243.

[32] Ibid., 244.

officer patrol.[33] The responsiveness of the first patrol unit reaching the scene was crucial to the success of arresting the burglars. When the first police patrol arrived at the crime scene within 4 minutes of alert being called, they were almost twice as successful in catching the burglars in the act (15.3 percent) as compared to when they reached the scene after 6 minutes (8.2 percent).[34] When the response times were longer than 10 minutes, which accounted for 5 percent of sample incidents, no burglars were caught.[35]

The other important finding from the study showed that when more patrol units responded to the emergency alert, more burglars were caught at or near the scene. On average, there was a capture when 3.3 patrol units attended, and the burglar escaped when 2.7 or less units reached the scene. When only a single patrol unit attended, the success rate of capture is only 5.2 percent, whereas when 5 or more units responded, over 20 percent of burglars were caught.[36] Also, it is interesting to note that the response times were associated, and partly depended on how many patrols responded, so that when more patrol units responded, the response times of the first patrols reaching the scene became shorter.[37]

The study confirmed that more patrol units deployed resulted in quicker response times and higher success rate of on-scene arrest. The problem is how to increase the number of patrol units without stretching the existing resource beyond limit. Coupe and Blake suggested that switching the 61 percent of double-crewed patrol units to single-crewed units will reduce the number of incidents and area covered per patrol, and the distance of the nearest patrol units from burglary scenes.[38] As a result, this measure would be

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[33] Coupe and Blake. "The effects of patrol workloads." *Journal of Criminal Justice*, 244.

[34] Ibid.

[35] Ibid.

[36] Ibid.

[37] Ibid.

[38] Ibid., 251.

expected to double the success rate of on-scene capture of burglars from 10 percent to 21 percent.[39]

These findings not only validated the importance of police response time in crime crackdown, they also revealed that the law enforcement department is in need of changing the way the patrol is being deployed. In order to make the change, the law enforcers need a new breed of transportation to enable them to be deployed in greater number of single-crewed patrol units that could help them to be more responsive, effective, and efficient in crime crackdown. These findings will have profound influence in the design of Rapid Deployment Emergency Services (RapiDES) vehicle which will be further described in later chapter.

2.6 Proposals to Minimize the Emergency Response Times

All these studies presented above highlight the importance of implementing measures to ensure the quickest response to emergency calls possible. Griffin and McGwin suggested several potential solutions to minimize the impact of traffic congestion on emergency response time such as in-vehicle pre-emptive green light devices (i.e., devices that will switch traffic lights ahead of the approaching emergency services vehicles to green, ensuring an open intersection for fast and safe passing), public education on how to react to approaching emergency services vehicles, and better roadway design such as the provision of high-occupancy lanes.[40]

These solutions have their own merits but also have shortcomings in each of them. According to the survey in their studies, only 15% of the EMS vehicles have in-vehicle pre-emptive green light devices installed.[41] It is suspected that the high cost of

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[39] Coupe and Blake. "The effects of patrol workloads." *Journal of Criminal Justice*, 251.

[40] Griffin and McGwin. "Emergency Medical Service." 402.

[41] Ibid.

implementation, operation and maintenance is the cause of relatively low number of EMS vehicles equipped with such devices. According to a study done by the Joint Program Office for Intelligent Transportation Systems of the U.S., “For a site, the structure, and the apparatus, the cost is about $3 million (2004 dollars); and the continuous operations and maintenance costs are about $2.5 million per year for each station.”[42] Furthermore, pre-emptive green light devices will be of little use in a gridlock situation, where all traffic comes to a standstill.

The solution of public education on how to react to approaching emergency services vehicles is relatively easier to implement through public awareness campaign. However it is difficult to obtain consistent result across population, especially in communities with mixed cultural backgrounds and educational levels of residents. Again, this solution will also be of little use in a gridlock situation, where civilian vehicles have no space to manoeuvre to make room for the emergency vehicles.

The other solution calls for the provision of high-occupancy lanes which were reported to be beneficial in reducing response times. However, the installation of these lanes is not feasible especially in developed areas due to resource constraints.[43]

2.7 Summary

In this chapter, the causes and consequences of traffic congestion have been reviewed and discussed. Among these consequences, the one with the most direct impact on the lives of people is the delay of emergency response times. The effects of emergency response times on various emergency services have been reviewed and discussed, and the conclusion is that rapid response times are critical to the safety of life and property of people. Then, several potential solutions to this problem have been proposed by

[42] United States, Joint Program Office for Intelligent Transportation Systems. *Traffic signal preemption for emergency vehicles : a cross-cutting study : putting the 'first' in 'first response'.* January 2006: 8-4.

[43] Griffin and McGwin. "Emergency Medical Service." 402.

some authors. However all of these have their pros and cons and do not solve the problem entirely. The search for a solution will continue in the next chapter where a major factor that affects the emergency response times which has not been addressed before will be discussed.

CHAPTER 3: PROBLEM DEFINITION

In this chapter, a factor that has been affecting the responsiveness of emergency response times which has never before been addressed will be discussed. This factor is the giant size of conventional emergency services vehicles relative to other vehicles and the space available on the road as will be illustrated. Having established this fact that size is a factor affecting emergency response times, the task is then focusing on searching for a design solution to overcome this problem with the help of research mapping exercise and scenario studies. Through these rigorous exercises, the design requirements and key features of RapiDES will be better understood and the design brief can then be generated.

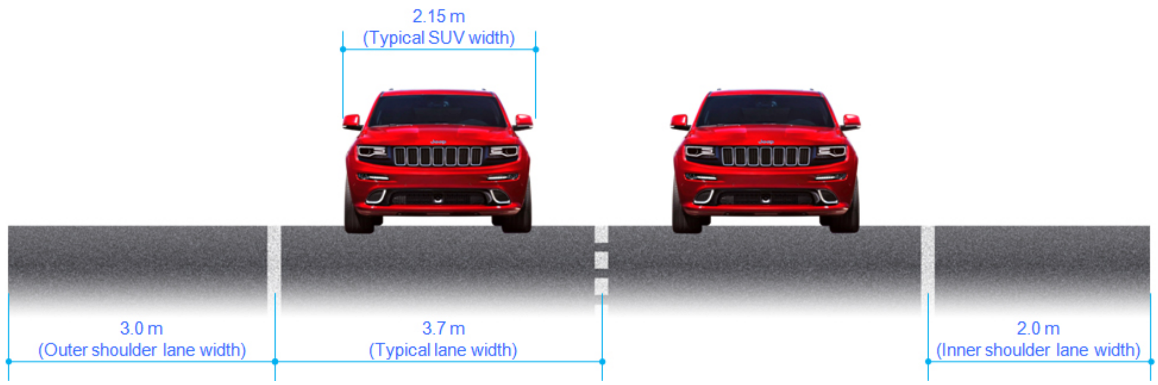
3.1 The Problem: Size Matters

Several potential solutions to minimize the impact of traffic congestion on emergency response times have been reviewed in the previous chapter. However, none of these solutions have addressed the fact that the size of conventional emergency services vehicles is a big part of the problem itself. The jumbo-sized ambulances are already much bigger than the average SUVs and pick-up trucks, not to mention the mammoth-sized fire engines, rendering them difficult to weave through heavy traffic especially during rush hours.

Let's take a look at the typical roadway design in the North America as shown in Figure 3.1 which is drawn to scale, based on the Highway Geometric Design Guide.[44] As illustrated, the roadway geometric design can comfortably accommodate two typical sized SUVs travelling in the same direction side by side in adjacent lanes.

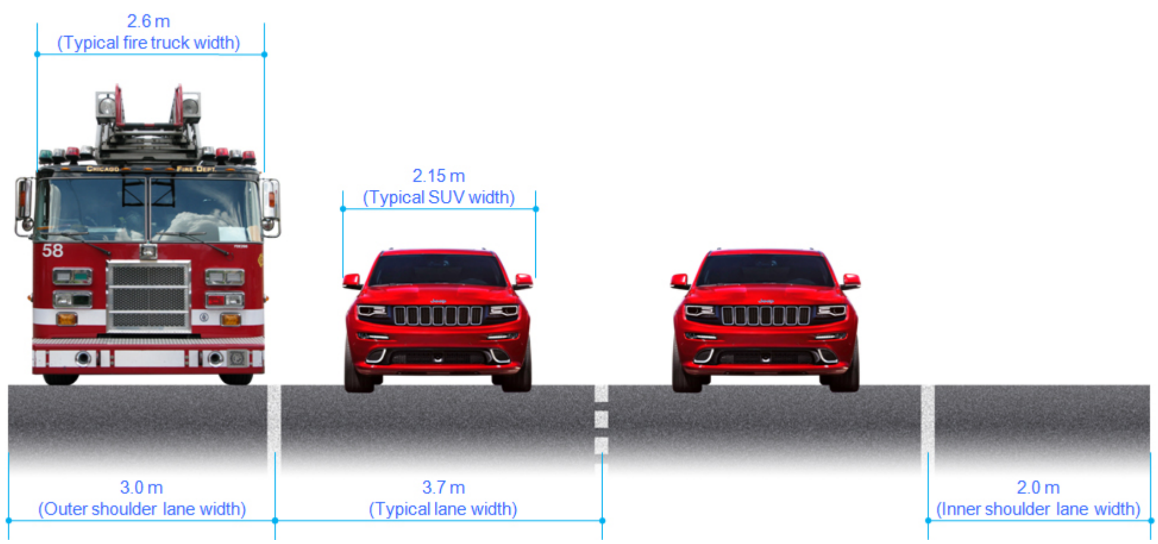
[44] Alberta Infrastructure. *Highway Geometric Design Guide: Chapter A: Basic Design Principles.* Design Guide, Alberta Infrastructure, 1999: A-21.

Figure 3.1. Typical Roadway Dimensions in North America.



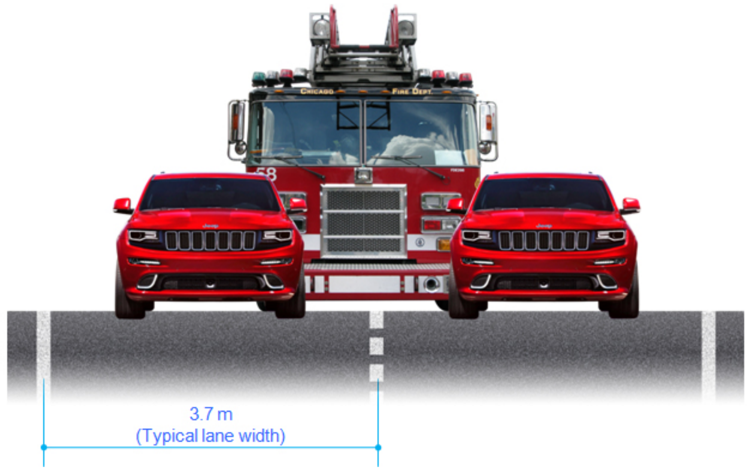
In Figure 3.2, when travelling on highway, the fire truck can still make its way through the traffic when the emergency shoulder lane is available.

Figure 3.2. Fire Truck Travelling on Highway.



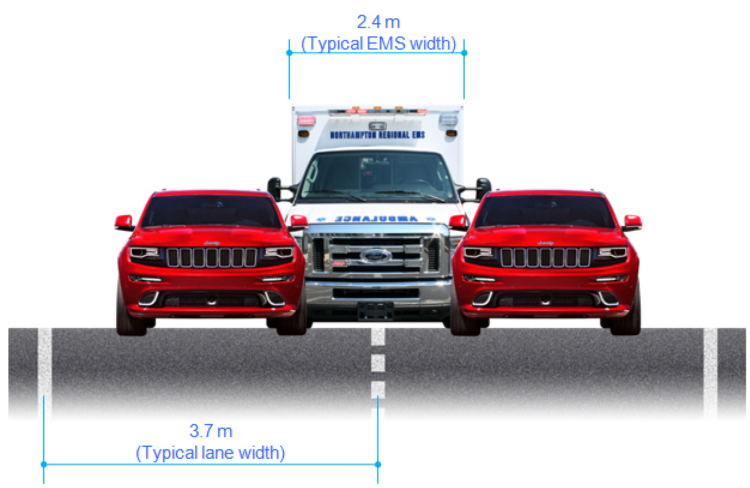
However, when the shoulder lane is not available especially on city streets, the mammoth-sized fire truck will have difficulty going through the traffic easily, as shown in Figure 3.3.

Figure 3.3. Fire Truck Travelling on City Street.



The ambulance travelling on city streets does not fare any better than the fire truck, as shown in Figure 3.4.

Figure 3.4. Ambulance Travelling on City Street.



While the mounted policemen on motorbikes can move through the traffic relatively easier, they can only ride their bikes when the weather permits. In the northern regions especially in most parts of Canada, that means only less than half a year's time for patrolling on bike. In addition, a motorbike does not have the capacity for all the needs of dealing with emergency situations for medical services and fire departments. For the police officers in Rochester, MN, who also act as the first responders for cardiac arrest patients most of the time, they need to bring the mobile defibrillator with them on patrol.[45] Motorbike simply cannot meet the requirements of today's demanding emergency challenges.

Therefore, it is imperative for a solution in the near future (2020) to address these issues for the emergency services to reduce the response times and to reach the scene of emergency safe and dry with the required equipments. The question is: how to figure out the best solution to the problem? In subsequent sections of this chapter, a research mapping exercise and a scenario study exercise will be carried out to help with searching for the solution.

3.2 Researching the Design Problem through a Mapping Exercise

Mapping exercise is very useful in research and design projects for it is "a way to hold a domain still for long enough to be able to see the relationships between the various approaches, methods, and tools. Maps are good for visualizing relationships. Maps can be useful for showing complexity and change."[46]

Figure 3.5 shows the mapping exercise carried out for visualizing the relationship between the causes and consequences of traffic congestion. As many stakeholders as possible are included in the map to provide a comprehensive overview of the picture. Potential solutions, some of which have been discussed in previous chapter are analyzed with pros and cons respectively. One potential solution proposes to "reduce the size of emergency services vehicles" has been identified as the most promising, resulting in the proposal of designing a Rapid Deployment Emergency Services (RapiDES) vehicle.

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[45] Davis, Robert. "The price of just a few seconds lost: People die." *USA Today.*

[46] Sanders, Liz. "An Evolving Map of Design Practice and Design Research." *Interactions: New Visions of Human-Computer Interaction* 15, no. 6 (November 2008): 13.

Figure 3.5. Research Mapping: Traffic Congestion – Causes and Consequences.

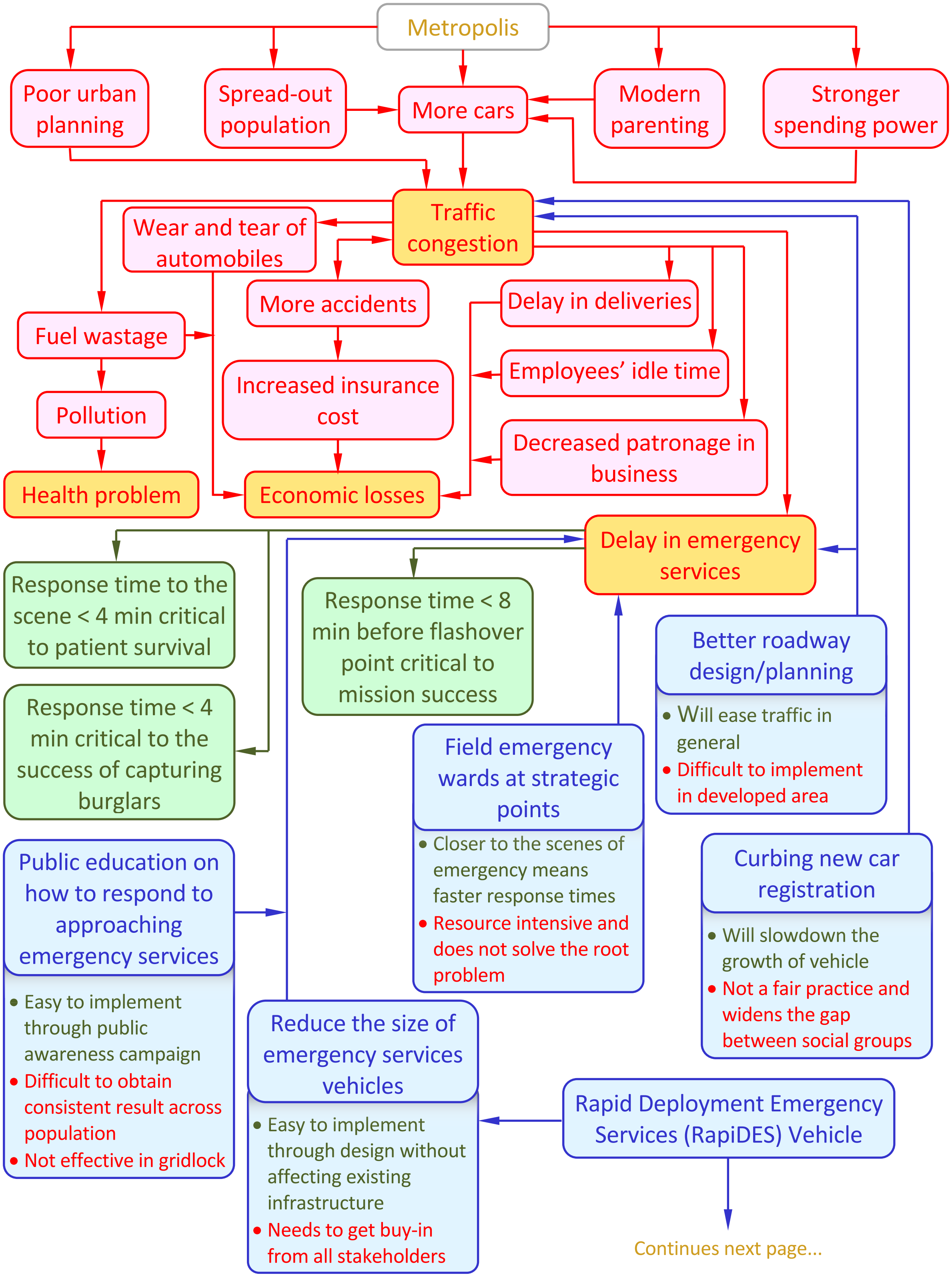

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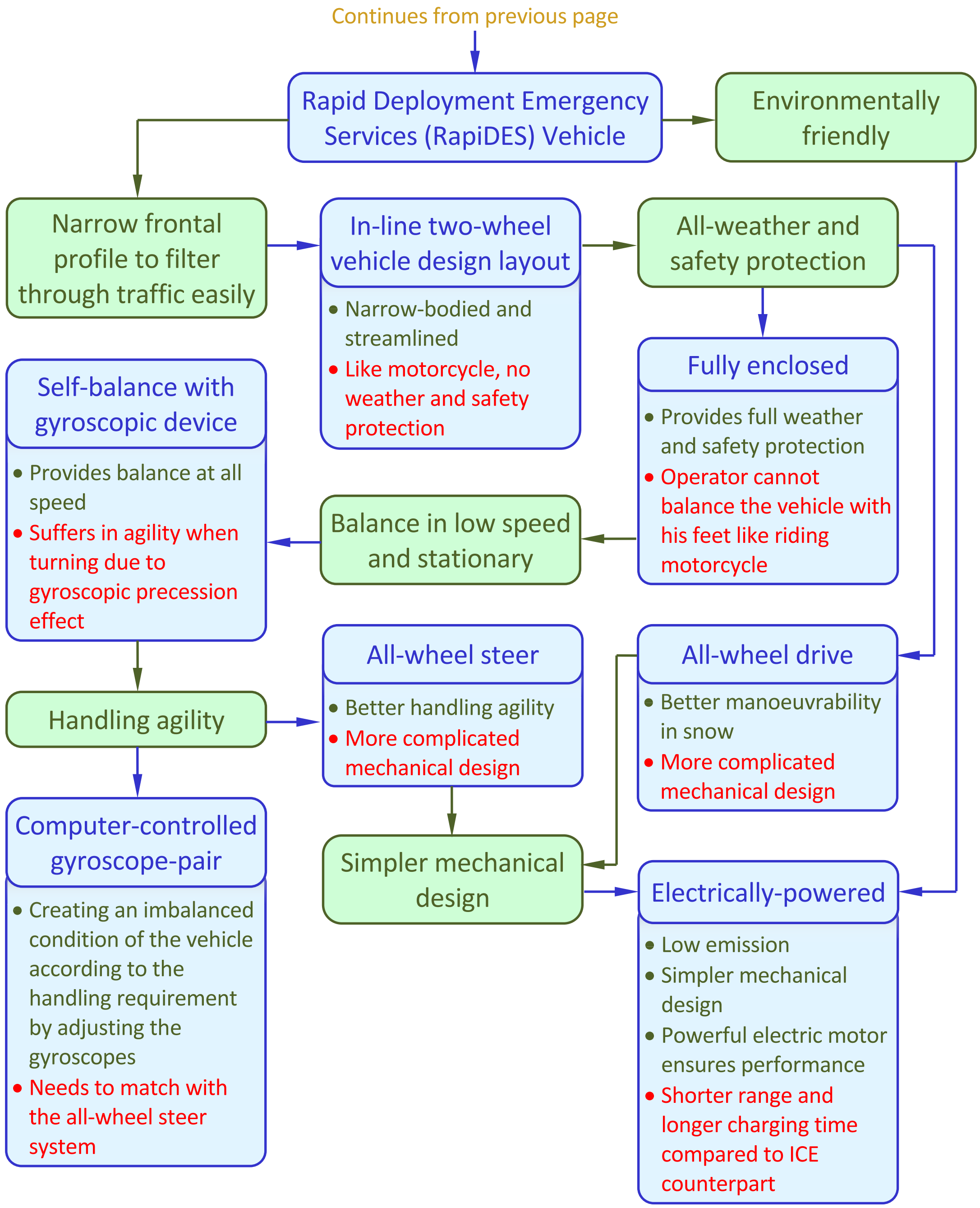
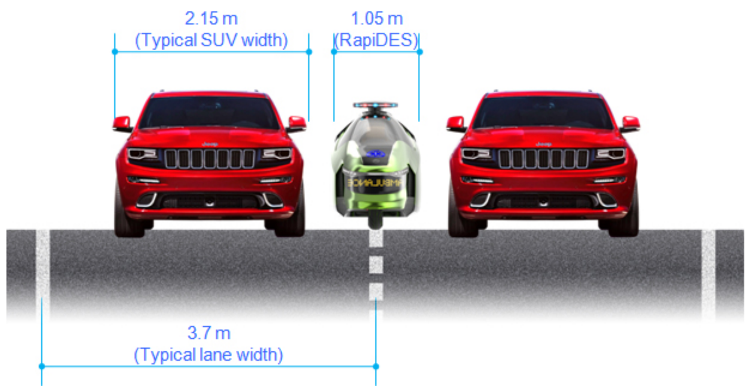
Figure 3.6. Research Mapping: Traffic Congestion – Improving Response Time.



The mapping exercise continues in Figure 3.6 which shows the logical thought process of formulating the basic requirements and key features of the design of RapiDES. The most important requirement of RapiDES is to have a narrow frontal profile, which is having a narrow body width, in order to be streamlined enough to filter through traffic effortlessly, even in a gridlock situation. Figure 3.7 shows that a narrow-bodied RapiDES will filter through (lane splitting) traffic with ease.

Figure 3.7. Narrow-bodied RapiDES filters through traffic easily.



3.3 Scenario Studies of RapiDES in Action

Several scenarios of RapiDES in action are developed for each of the three emergency services of EMS, fire department, and police. These scenarios, set in the year of 2020 will attempt to simulate the situations and conditions of the operations of emergency services, and hopefully provide better understanding of the requirements and features for the design of RapiDES.

Scenario study is a commonly used approach to help strategic analysis and decision making by organizations and individuals. According to Wright and Cairns, "Scenario thinking using the intuitive logics method is a systematic way of looking into the future, and one that is focused on perceptions of the causal unfolding of events. As such, scenario thinking has a strong basis centered on providing an explanation of the course of future events."[47]

Scenario 1 (EMS): Two paramedics travelling in two separate RapiDES filter through heavy traffic to arrive at the scene of an accident on highway. They perform some basic life support treatment on the injured person. They determine that the patient needs to be hurried to the hospital immediately but the ambulance will not make it in time due to traffic congestion. They carefully load the patient into one of the RapiDES and then set it on auto-pilot mode to the nearest hospital. The two paramedics then travel back in the other RapiDES.

Scenario interpretations:

- RapiDES is slim enough to filter through heavy traffic.
- RapiDES has the capacity to carry emergency medical equipment to provide basic life support treatment and a stretcher.
- RapiDES can carry a patient lying in stretcher to the hospital in auto-pilot mode.
- RapiDES is able to carry two 95th percentile male adults (which is about 189 cm in the United States).[48]

Scenario 2 (Fire Department): Two firemen arrive at the scene of a burning low rise building in two RapiDES. One fireman uses the built-in light aerial ladder to evacuate the victims in the building. The stability of the already gyro-stabilized vehicle is further improved with the expanded landing gears. The other fireman connects his RapiDES to the nearest fire-hydrant and chain to the other RapiDES with hose so that both units

[47] Wright, George, and George Cairns. *Scenario Thinking: Practical Approaches to the Future.* New York: Palgrave Macmillan, 2011, 16.

[48] Fryar, Cheryl D, Qiuping Gu, and Cynthia L Ogden. *Anthropometric reference data for children and adults: United States, 2007–2010.* Statistics, Hyattsville, Maryland: National Center for Health Statistics, 2012.

have water supply. They then use the impulse fire extinguishing system (IFEX)[49] on the vehicles to highly pressurise the water into a vaporized mist at high velocity which is more efficient in putting off the fire. The light aerial ladder comes in handy to provide an elevated stream that is also more efficient in fire fighting. The victims are rescued and the fire is under control before it reaches the flashover point.

Scenario interpretations:

- RapiDES has enough capacity to house the IFEX equipment and hose reel of up to approximately 50 meters.
- RapiDES can be chained and linked with hoses to share the water supply from a single fire hydrant.
- RapiDES has capacity to house a light weight aerial ladder.
- RapiDES has a pair of retractable landing gears that is expanded when using the aerial ladder to improve stability.

Scenario 3 (Police): On one snowing evening, a burglary in progress is being reported. Several police patrols in RapiDES near the vicinity respond to the alert and rush to the scene. The first patrol unit manages to arrive at the scene in just less than three minutes. The two burglars are surprised by the rapid response of the police, abandon the burglary act and try to escape in their car. The first patrol unit quickly marks the escaping vehicle with the on-board tagging and positioning system, and shares the information with supporting units which are rushing to the scene from different directions. These various patrol units are now aware of the position of the target vehicle as well as their colleagues' vehicles. They are being directed under computer guidance and a positioning system to plan for the best route of intercepting the target vehicle.

[49] Azure Solutions, Inc. "How IFEX Works." *Azure Solutions, Inc.* 2015. http://www.azuresol.com/howIFEXworks.htm (accessed June 19, 2015).

RapiDES is much more agile in handling in snow condition and is a high performance vehicle. The runaway car is no match against the RapiDES in performance and handling especially in snow. The escaping vehicle is finally surrounded by a total of five RapiDES, and with no hope of escaping, the burglars turn themselves in. The whole incident is over in less than ten minutes.

Scenario interpretations:

- RapiDES is equipped with state-of-the-art positioning and tracking systems that allows a number of units to hunt down the suspect in wolfpack-like deployment.
- RapiDES is an all-weather vehicle that provides protection against harsh weather in northern region.
- RapiDES also handles well in bad weather condition thanks to the all-wheel-drive and all-wheel-steer systems coupling with the computer-controlled gyroscopic balancing system that constantly monitors and adjusts the precession effect of the two gyroscopes to create imbalanced state to help the vehicle turning corners and negotiating into bends much faster.
- RapiDES is equipped with powerful electric motors which can match the speed of many sports cars.

3.4 Key Features and Design Requirements of RapiDES

Having gone through the research mapping and scenario study exercises, the design requirements and key features for the design of RapiDES are generated and can be referred to in the Design Brief of RapiDES in Appendix A, which serves as the basis for the next stage of design work.

3.5 How About a Three-Wheeler?

The other possible configuration for a narrow-bodied vehicle is a three-wheeler. In the past, three-wheel vehicles were usually wider and less stable in cornering for the consideration as a potential configuration layout for RapiDES. But a rather recent design of a three-wheeler concept from Toyota, i-Road (Figure 3.8), revealed in 2013, is as narrow as a motorcycle. The "Active Lean"[50] technology will automatically select the optimum lean angle based on speed, gyroscope angle, and steering input, by actuating the front left and right suspensions up and down, allowing it to lean into a corner much better and more stable than conventional three-wheelers.

Figure 3.8. Toyota i-Road. Digital image. Wired. March 5, 2013. Accessed August 23, 2015. http://www.wired.com/2013/03/toyota-i-road/

However, this project will choose the configuration of inline two-wheel layout over the three-wheeler for the following considerations:

1. Traditionally, the impression of a three-wheeler is comical, most notably represented by the blue colour Reliant Regal (Figure 3.9) in the British comedy series Mr. Bean, which got tipped over numerous times in several episodes. This comical impression is not helpful in building a cool and savvy image that RapiDES

[50] Lavrinc, Damon. "Toyota's Tiny EV Has 3 Wheels — But Feel Free to Lean Into Corners." *Wired.* March 5, 2013. http://www.wired.com/2013/03/toyota-i-road/ (accessed August 23, 2015).

would like to associate with. Furthermore, three-wheelers in some developing countries known as auto-rickshaws are associated with the image of poverty and backward, which is also not a good reason for this choice.

Figure 3.9. Reliant Regal as featured in Mr. Bean. Digital image. IMCDB. Accessed August 23, 2015. http://www.imcdb.org/vehicle_7718-Reliant-Regal-Supervan-III-1972.html

2. Even though Toyota i-Road's "Active Lean" technology makes a three-wheeler leaning into a corner better than conventional three-wheelers, bear in mind that this is done at a relatively lower speed (the vehicle has a maximum speed of only 60 km/h in Japan and 45 km/h in Europe).[51] Negotiating corners and bends at higher speed will not be stable for three-wheelers, which will be required to perform by RapiDES as has been discussed in scenario study earlier.

Therefore, from the aspect of cool factor and also the requirements of agility, stability and performance, the configuration of inline two-wheel gyro-stabilized vehicle design will be pursued in this project.

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[51] Toyota. "Toyota i-Road." *Toyota.* http://www.toyota-global.com/innovation/personal_mobility/i-road/ (accessed August 23, 2015).

3.6 Summary

In this chapter, the fact that the size of conventional emergency vehicles is part of the problem itself that causes the delay of emergency services response times has been reviewed. Having established this fact, a research mapping exercise and a scenario study exercise have been carried out to study possible solutions and better understand the demands and requirements of emergency services operations in the year of 2020. Through these exercises, the design requirements and key features of RapiDES are formulated in the Design Brief of RapiDES (Appendix A) and serves as the basis for the next stage of design work. Also, the exclusion of a three-wheel configuration has been reasoned.

CHAPTER 4: PRECEDENT-BASED RESEARCH

In this chapter, the brief history and the current development of gyro-stabilized vehicle will be examined in order to provide a foundation upon which the design of RapiDES is worked on. These precedent cases of design show the different configurations of gyroscope in the vehicles, and the most current design C-1 from Lit Motors shows a good example of the integration of microelectronics and computing technology with gyroscope that sets the standard for future development of such vehicles.

4.1 Gyro-stabilized Vehicles: Early 20th Century

At the time when motor vehicles were still in their infancy at the turn of the twentieth century, a number of inventors were dreaming of motor vehicles travelling on inline wheels that were kept upright and stable with the aid of gyroscopes. Louis Brennan filed his first gyroscopically stabilized monorail patent in as early as 1904.[52] On November 11, 1909, Brennan successfully demonstrated a full-sized monorail car balanced by two contra-rotating gyroscopes in England,[53] as shown in Figure 4.1. The car travelled on a single rail around a circular track about 220 yards in perimeter at a speed of 25 mile per hour, carrying a load of 40 passengers on its platform where they were free to move around.[54] Despite numerous successes in demonstration to scientists, engineers, and military officers, fear of failure in the gyroscopes that would cause disaster to the car travelling in high speed prevented the invention developed beyond the prototyping phase.[55]

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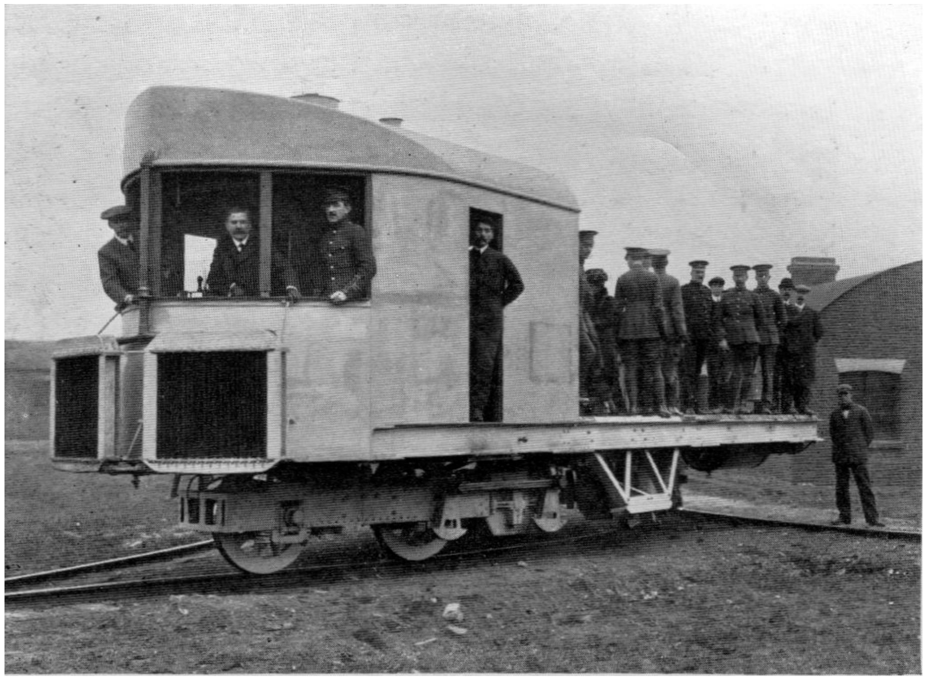
[52] Brennan, Louis. Means for imparting stability to unstable bodies. United States of America Patent US796893 A. August 8, 1905.

[53] Eddy, Henry Turner. "Mechanical principles of Brennan's monorail car." *Scientific American Supplement* 72 (1911): 467.

[54] Eddy, Henry Turner. "Mechanical principles of Brennan's monorail car." 468.

[55] The Monorail Society. "Monorails in History-Part I." *The Monorail Society.* http://www.monorails.org/tMspages/History.html (accessed June 22, 2015).

Figure 4.1. Brennan's monorail. Scanned from: Hartnell, F.S. *All About Railways*. London: Cassell, Circa 1910 – 1916. Scanned by Andy Dingley. Accessed June 22, 2015. https://commons.wikimedia.org/wiki/File:Brennan_monorail_(All_About_Railways,_Hartnell).jpg

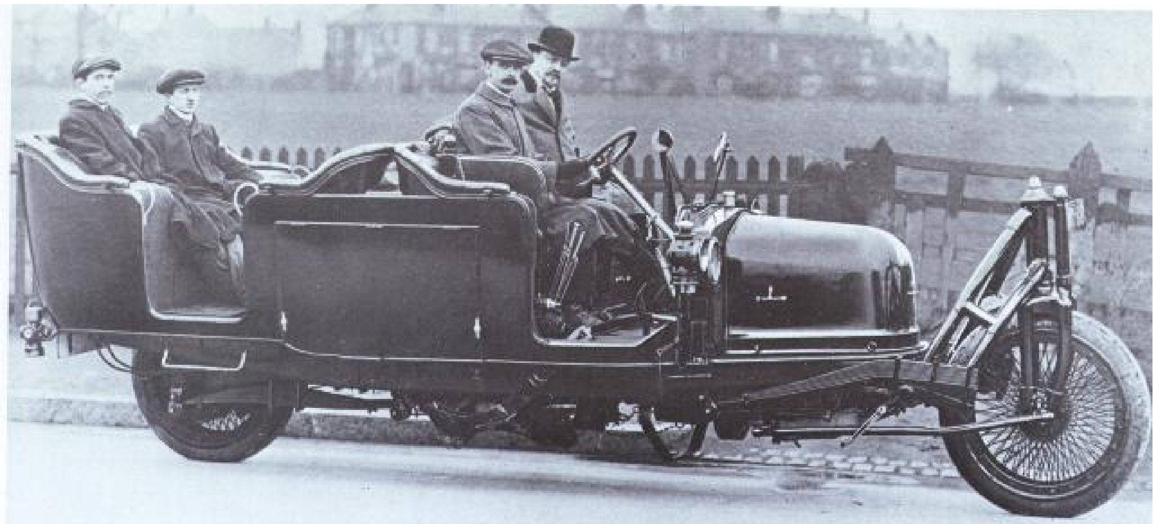


In 1912, a Russian aristocrat Pyotr Shilovsky commissioned Wolseley Tool And Motorcar Company to build his design of a gyrocar. In 1914, the prototype was successfully demonstrated to the public in London,[56] as shown in Figure 4.2. Instead of using two contra-rotating gyroscopes like in Brennan's monorail, Shilovsky's gyrocar used one gyroscope spinning at a rate much slower than Brennan's.[57] Shilovsky claimed that the gyrocar would be able to cross terrain where 4-wheel vehicles would not, and it would require less power to reach a certain speed. Shilovsky claimed that these attributes would make the vehicle appealing to the military, but in actuality, neither of them

[56] "How New Gyro Car Worked in London." *The New York Times.* May 17, 1914. http://query.nytimes.com/mem/archive-free/pdf?res=9E07E3D9173AE633A25754C1A9639C946596D6CF (accessed June 22, 2015).

[57] "The Schilovski Gyrocar." *The Museum of Retro Technology.* July 20, 2004. http://www.aqpl43.dsl.pipex.com/MUSEUM/TRANSPORT/gyrocars/schilovs.htm (accessed June 23, 2015).

Figure 4.2. Schilovsky's gyrocar. Digital image. The Museum of Retro Technology. July 20, 2004. Accessed June 23, 2015. http://www.aqpl43.dsl.pipex.com/MUSEUM/TRANSPORT/gyrocars/schilovs.htm.



seemed convincing.[58] The vehicle weighted 2.75 tons on two wheels, which was not promising for the muddy Eastern Front. The vehicle was also said to suffer from a very large turning radius, which was also not favorable as a proposed military vehicle.[59] After the First World War broke out in the same year, Shilovsky returned to Russia and the project was never pursued any further.[60]

4.2 Gyro-stabilized Vehicles: In the 1960s & 1990s

Fast forward in time to 1961, when Ford first showed its Brennan inspired, futuristic inline two-wheel gyrocar, dubbed Ford Gyron at the Detroit Motor Show as a concept car designed by the legendary designer Syd Mead, whose rendering of the car is shown in Figure 4.3. Ford created this concept car (Figure 4.4) mainly for the purpose of research and marketing with no intention of putting it into production.[61]

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[58] "The Schilovski Gyrocar." *The Museum of Retro Technology*.

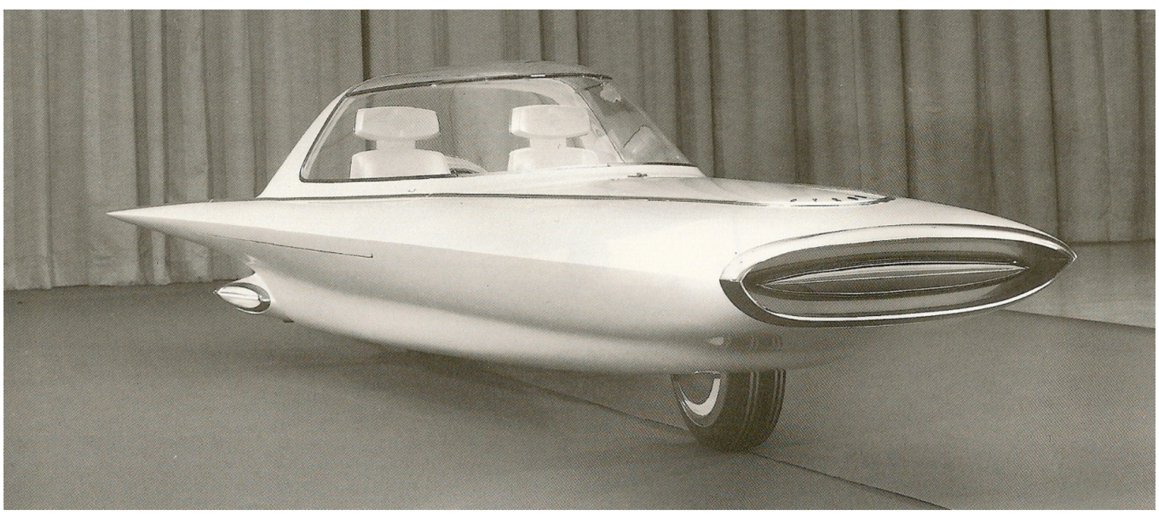
[59] Ibid.

[60] Ibid.

[61] "Ford Gyron." *Wikipedia.* December 2009. https://en.wikipedia.org/wiki/Ford_Gyron (accessed June 23, 2015).

Figure 4.3. Mead, Syd. Rendering of Ford Gyron. Digital image. Car Styling. Accessed June 22, 2015. http://www.carstyling.ru/en/car/1961_ford_gyron/images/6208/

Figure 4.4. Ford Gyron in 1961. Digital image. Car Styling. Accessed June 22, 2015. http://www.carstyling.ru/en/car/1961_ford_gyron/images/15438/

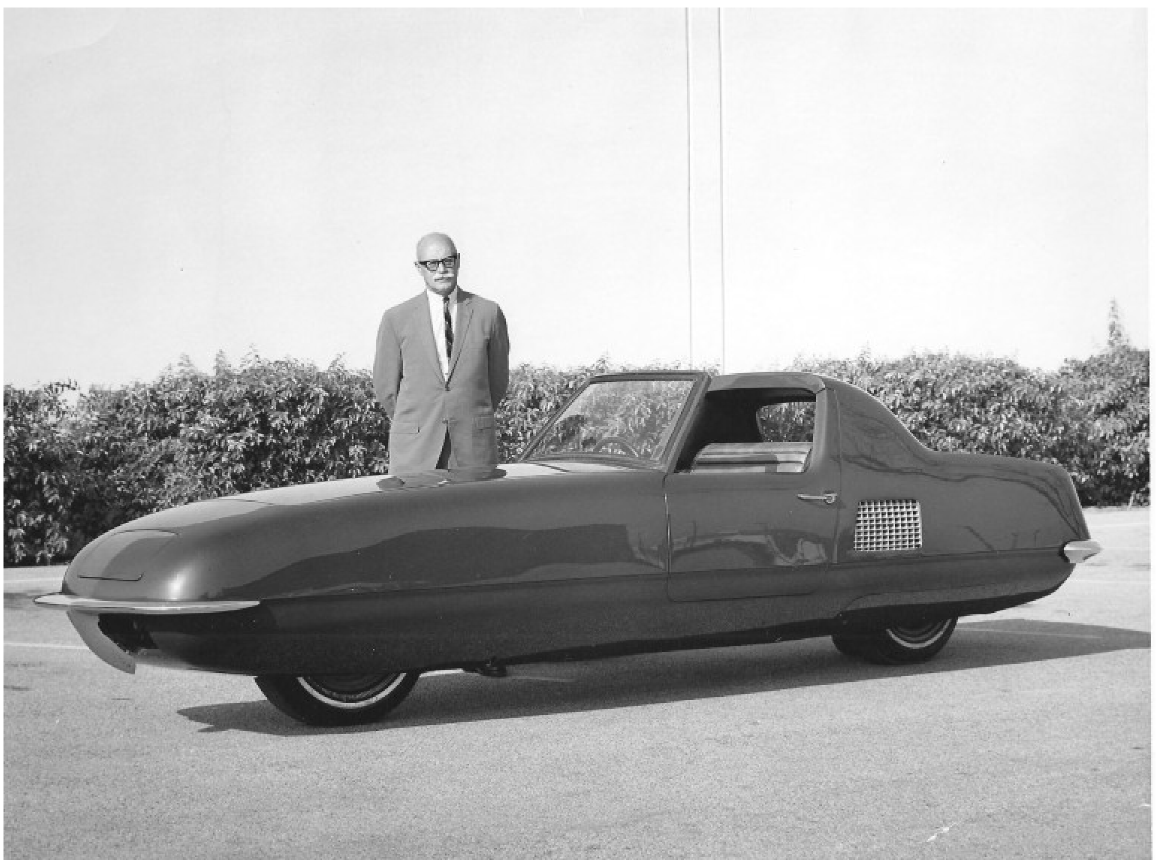


In 1967, a California-based company Gyro Transport Systems built another gyro-stabilized prototype car known as the Gyro-X.[62] The vehicle was invented by Thomas O.

[62] Coxworth, Ben. "Bizarre self-balancing 1967 Gyro-X car to be restored." *Gizmag.* February 26, 2013. http://www.gizmag.com/gyro-x-gyroscopic-car-restoration/26427/ (accessed June 30, 2015).

Summers[63] and designed by the renowned industrial designer Alex Tremulis, who had involved in the Ford Gyron project six years ago. Both designs share some similarities in the aspect of future-retro styling, as shown in Figure 4.5. However, the biggest difference between the two is that while Ford Gyron was a double-seat vehicle, Gyro-X was a single seater, effectively making it narrower than its predecessor. Another difference is the number of gyroscopes in use: Ford Gyron had two while Gyro-X only needed one. The company went bankrupt before they could bring Gyro-X into production.[64]

Figure 4.5. Designer Alex Tremulis with the Gyro-X. Digital image. Gizmag. February 26, 2013. Accessed June 23, 2015. http://www.gizmag.com/gyro-x-gyroscopic-car-restoration/26427/pictures#3



[63] Summers, Thomas O. Gyro Vehicle. United States of America Patent US3373832. April 19, 1966.

[64] Coxworth, Ben. "Bizarre self-balancing 1967 Gyro-X car to be restored." *Gizmag.*

In 1993, a company called Roadhawk Enterprises advertised in some kit car magazines selling a video and info pack for a gyroscopically stabilized vehicle dubbed the Gyro Hawk (Figure 4.6).[65] According to various comments posted to the Cobb's blog, the creator of Gyro Hawk David Ryker was mentored by the gyro-dynamics genius of Gyro-X, Thomas Summers. Ryker would sell Gyro Hawk as a kit for USD10K, but was considered too expensive by potential buyers. As can be seen in Figure 18 and a YouTube video[66], the vehicle was retrofitted with a motorcycle without the front steering assembly as the driving unit. As a result it has a rather long wheelbase as compared to conventional motorcycles. In the video, the vehicle was performing twist and turn in an empty parking lot flawlessly, albeit rather slowly.

Figure 4.6. The Gyro Hawk advertisement. Digital image. Stephen Cobb's Gyro Car Blog. January 11, 2007. Accessed June 23, 2015. http://gyrocar.blogspot.ca/2007/01/gyro-hawk-what-was-it-and-where-did-it.html

[65] Cobb, Stephen. "The Gyro Hawk: What was it and where did it go?" *Stephen Cobb's Gyro Car Blog.* January 11, 2007. http://gyrocar.blogspot.ca/2007/01/gyro-hawk-what-was-it-and-where-did-it.html (accessed June 30, 2015).

[66] "1993 Gyro Cycle – the Gyro Hawk," YouTube video, 2:19, posted by "Thrustcycle," August 9, 2012, https://www.youtube.com/watch?v=xKcWfD6kT1w. (accessed June 30, 2015).

4.3 Gyro-stabilized Vehicles: Current Development

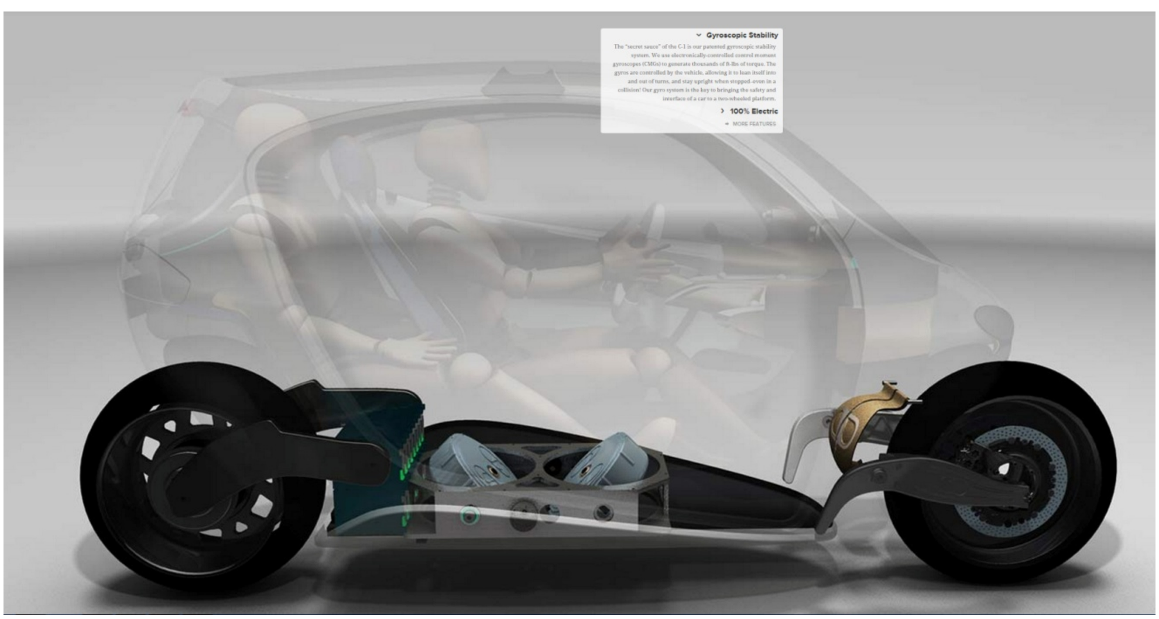
To date (July 2015), it is known that there are two separate developments of gyro-stabilized single track two-wheel vehicle: Thrustcycle's SRT (Figure 4.7) and Lit Motors' C-1 (Figure 4.8). Both of them have demonstrated their prototypes in various YouTube videos. Lit Motors' C-1 looks far more refined than Thrustcycle's SRT. Both have been in development for quite a number of years, but have not yet seen the light for production. C-1 was scheduled for production by the end of 2014, but as of this writing (July 2015) there is no prospect of seeing one on street by the end of this year. From various comments posted online, C-1 seems to have a huge level of acceptance in the concept, but not the asking price of USD24K.

Figure 4.7. Thrustcycle's SRT. Digital image. Gizmag. December 9, 2011. Accessed June 24, 2015. http://www.gizmag.com/thrustcycle-srt-new-version/20805/

Figure 4.8. Lit Motors' C-1 with founder Daniel Kim behind the wheel. Digital image. Green Car Reports. March 26, 2014. Accessed June 24, 2015. http://www.greencarreports.com/image/100461110_lit-motors-c1

Nevertheless, the design of C-1 injects some fresh air into the century-old idea of gyro-stabilized vehicle with the advent of computing technology and microelectronics, making the vehicle safer, smarter and greener. It's placement of a pair of gyroscopes underneath the seat (Figure 4.9) also serves as a good reference for the package layout design of RapiDES, as will be discussed in the following chapter.

Figure 4.9. Lit Motors' C-1 showing placement of gyroscope. Digital image. Lit Motors. Accessed June 23, 2015. http://litmotors.com/c1/



In short, both developments (and those before them) claim the benefits of gyroscopically stabilized single-track two-wheel vehicle as the following[67] [68]:

- Light weight therefore energy efficient.
- Freedom of a motorcycle (lane splitting where it is legal in some states in the U.S.).
- Requires minimum parking space like motorcycle.
- Shields the operator from exposing to the elements.
- Provides car-like comfort and safety.
- Less wear and tear to the tires as compared to those four-wheel vehicles.
- Braking energy is transferred to the gyroscopes and stored for later acceleration.
- Vehicle leans into curve much easily with the help of gyroscopes and microelectronics.

These benefits stated above are all well established and are also cohesive with the purpose of this thesis/project. However, as to why gyro-stabilized single track two-wheel vehicles have not caught on with the market is still unknown and may require more in-depth study into this area. It is speculated that one of the reasons could be that the general public feels less secured psychologically with something that is not stable in nature. Therefore, it is suggested that for these vehicles to be successfully marketed, it should be piloted with the uniformed units such as the emergency services discussed in previous chapters, for uniformed units usually have stronger mental power to overcome psychological barrier than the general public.

This successful implementation in law enforcement has been seen in Segway (Figure 4.10) where it is used to decrease response time and deter crimes in environments

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[67] "Gyroscopically stabilized vehicles with KERS (patents pending)." *Thrustcycle.* 2012. http://www.thrustcycle.com/gyro-flywheel.html (accessed July 1, 2015).

[68] "C-1." *Lit Motors.* http://litmotors.com/c1/ (accessed July 1, 2015).

ranging from airports, shopping malls, event centers, and campuses.[69] Segway's founder Dean Kamen predicted in 2001 that Segway "will be to the car what the car was to the horse and buggy."[70] This prediction did not really come true as it is a fact that after 14 years Segway is more successful in niche market such as law enforcement than in consumer market. But I would still like to propose that "RapiDES will be to the police patrolling in car what Segway is to the police patrolling on feet."

Figure 4.10. Police officers patrolling on Segway. Digital image. Hawthorne Police. Accessed September 16, 2015. http://hawthornepolice.com/community-affairs-unit/

[69] "Case Studies: An In-Depth Look at Segway Patroller Applications ." *Segway.* 2014. http://www.segway.com/patrol/for-patrol/case-studies.html (accessed July 1, 2015).

[70] Regan, Michael P. "Segway sets course for stock market." *USA Today.* May 30, 2006. http://usatoday30.usatoday.com/tech/news/techinnovations/2006-05-30-segway-ipo_x.htm (accessed July 1, 2015).

4.4 Summary

In this chapter, the past designs and current development of gyro-stabilized vehicles have been reviewed. These precedent designs provide a good understanding of the working mechanics of different configurations of gyroscopes in vehicle stabilization. In particular the placement of gyroscopes in Lit Motors' C-1 and its integration of state-of-the-art computing technology serve as a good reference for the design of RapiDES, which helps to accelerate the design process by shortening decision making phase. A quick speculation on why these precedent designs did not develop past the prototyping stage is made, and the solution to pilot the gyro-stabilized vehicle such as RapiDES with the emergency services is proposed. Up to this point, the solid groundwork for the design of RapiDES has been laid and will make the actual creative process of design much easier, as will be discussed in the next chapter.

CHAPTER 5: CONCEPT GENERATION & DETAIL DESIGN

In this chapter, the actual creative process of the design of RapiDES will now take place, starting with first defining the keywords for design direction. Once these keywords are defined, images reflecting these keywords are collaged that form an inspiration board upon which concept ideation in the form of sketches will be generated. This process of design is particularly iterative, bouncing between creation and reflection in order to achieve a design that is right for the purpose and context as described in the design brief. The final sketches are then imported into a 2D program where the definitive design curve lines will be drawn to include the two 95th percentile male manikins. These design curve lines in three orthographic views will serve as references for 3D modeling in a CAD program. The CAD models are then prepared separately for 3D printing and 3D rendering.

5.1 Concept Exploration

The concept exploration phase starts with finding a few keywords for setting the overall direction for the design. These keywords and the meaning significant to the design are as follows:

1) Aggressive: a vehicle for uniformed units particularly for the law enforcers should impose a rather aggressive and authoritative image and stance;
2) Streamlined: in order to swim through the oceans of traffic, the design has to be streamlined;
3) Precision: the vehicle is a masterpiece of precision design and fabrication, performing flawlessly in every action it takes;
4) Agility: the vehicle is extremely agile in operation, dodging obstacles and evading dangers effortlessly;
5) Versatility: the vehicle is versatile to be customized to perform many different tasks;

6) Smart: the vehicle is built with the state-of-the-art microelectronics and computing technology.

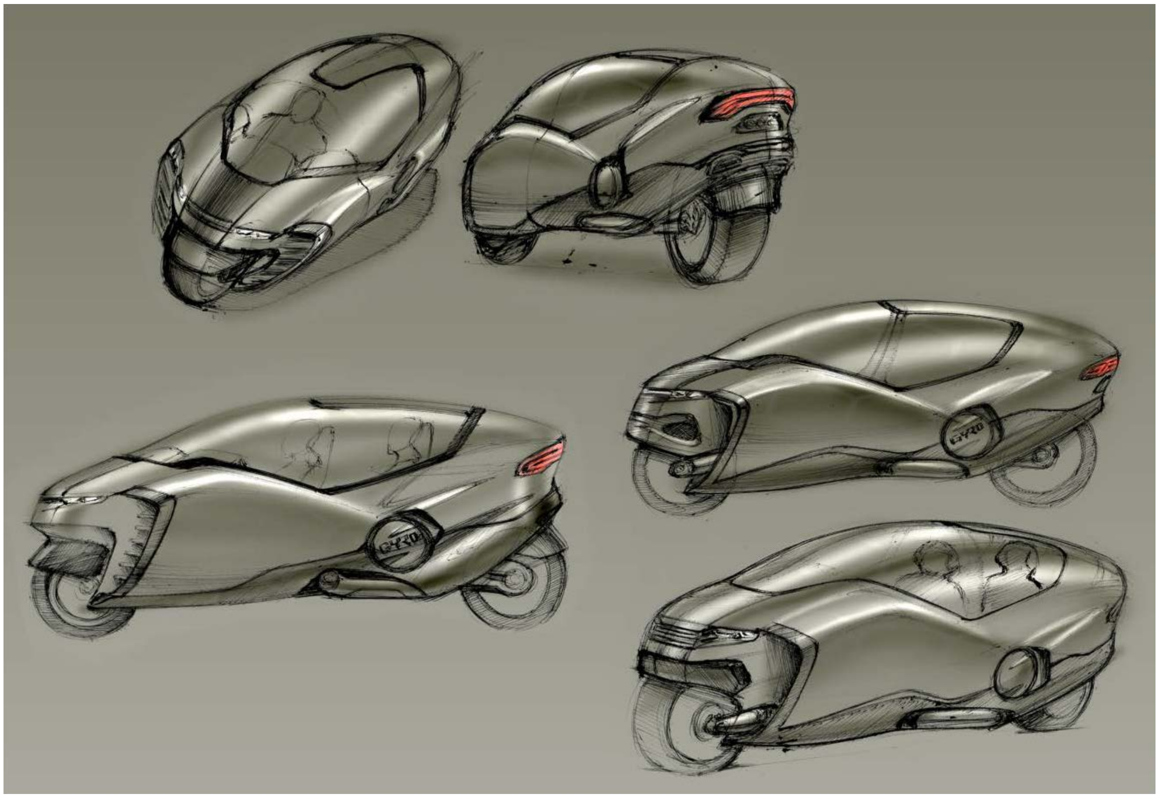
Once these keywords have been defined, the relevant images were collaged to form an inspiration board or mood board (Figure 5.1). This board is useful for finding visual cues when sketching and exploring design concepts. The process of concept exploration can take quite some time, depends on the level of design satisfaction the sketches achieve. The actual concept exploration phase of RapiDES spanned about more than half-a-year from the time the first sketch was made to the final sketch before the design was nailed down. Of course, I must admit that the activity of concept exploration was not carried out in full time during this half year period; otherwise this process could have been accelerated.

Figure 5.1. Inspiration board of RapiDES. Digital images collaged from various sources.

Figure 5.2. Sketches inspired by attack helicopters.

Figure 5.2 shows a concept exploration direction inspired by the motif of attack helicopters. Particularly, I was fascinated by the seating layout of the pilot and co-pilot in these helicopters, where the pilot is usually seated in the rear while the co-pilot is seated in the front, giving more protection to the pilot and better field of view to the co-pilot who is usually the gunner. Thus, the rear seat is raised to give the pilot some reasonable field of view. There are some interesting concept sketches inspired by this motif which could be developed into interesting design for RapiDES. However the overall feel of this design direction is too faceted and contradicting one of the keywords for design direction, Streamlined. Consequently, this design direction has to be abandoned. The concept exploration then continues with the more streamlined direction, while maintaining the gist of the other keyword: aggressive, as shown in the sketches in Figure 5.3.

Figure 5.3. More streamlined sketches of RapiDES.



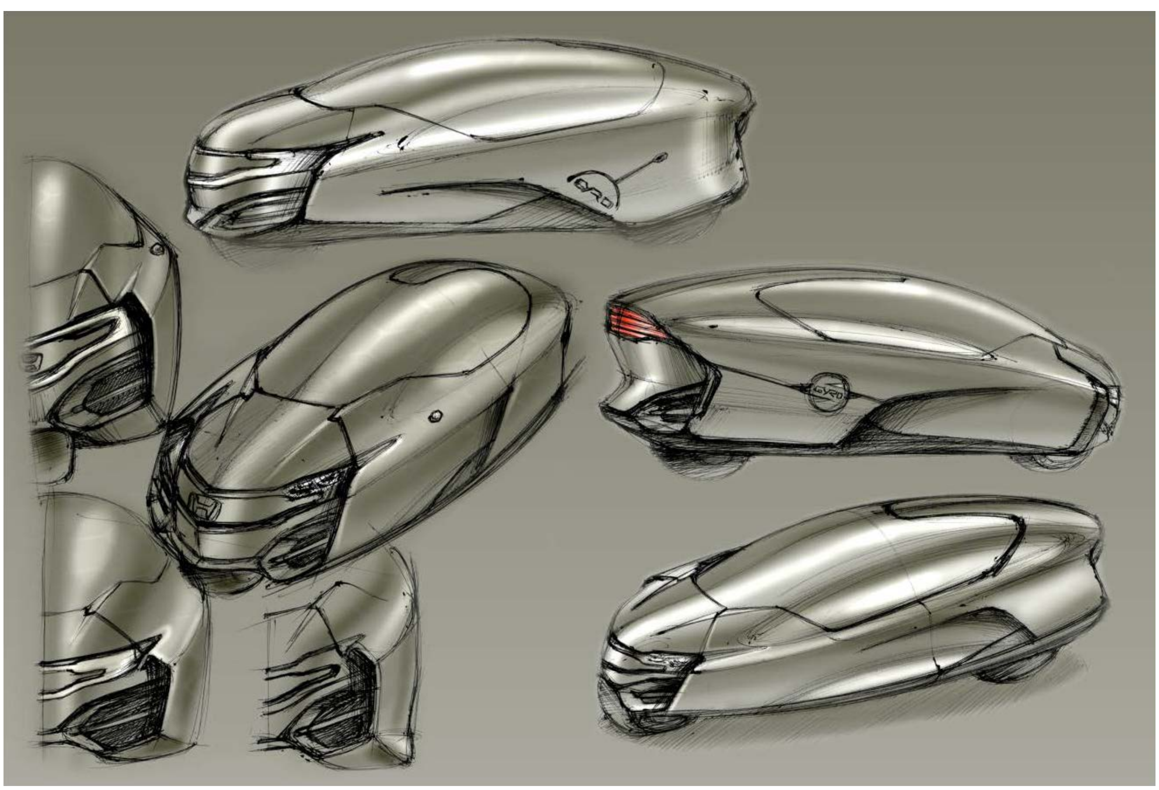
The design is starting to take shape in these sketches, but the front wheel is too exposed and too prominent for my liking, and the sculpted body is too muscular. Therefore these features are being toned down, as shown in the sketches in Figure 5.4.

The overall feel of the design is getting closer to what I want in a vehicle like RapiDES. Maybe the air-intakes inspired by the jet fighters at both sides of the body are a little too exaggerated. Also, the rear end of the body needs some different treatment other than the smooth and plain look. This area needs to be worked at in the subsequent exploration sketches, as shown in Figure 5.5.

In Figure 5.5, the side air-intakes are brought in closer to the body, and some experiment is done at the rear end. A few explorations on the headlight design and how it integrates with the side air-intakes are also done. Some air scoop elements are being

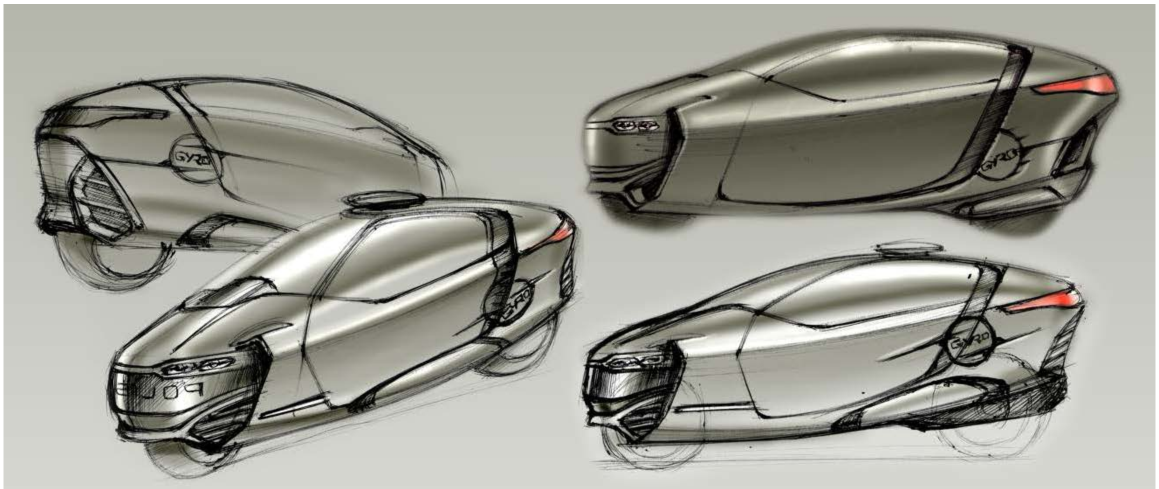
Figure 5.4. Toned down sketches of RapiDES.

Figure 5.5. Adjusted side air-intakes of RapiDES.



explored at the middle section of the body, but I feel they become too repetitive of the air-intakes at the front end. This needs to be corrected in subsequent sketch activity.

Figure 5.6. Final sketches of RapiDES.



Finally, the design is more or less nailed down as shown in Figure 5.6. The landing gears at the middle section are being moved towards the rear end as shown in the top right sketch. The flashing siren of emergency services is added on the top of the vehicle. The other design element I have been toying with but have not found a good solution is the way to integrate the symbol of gyroscopic stabilization into the design of RapiDES. This element will most probably be dropped from the final design (3D model) if a good solution has not been found by then.

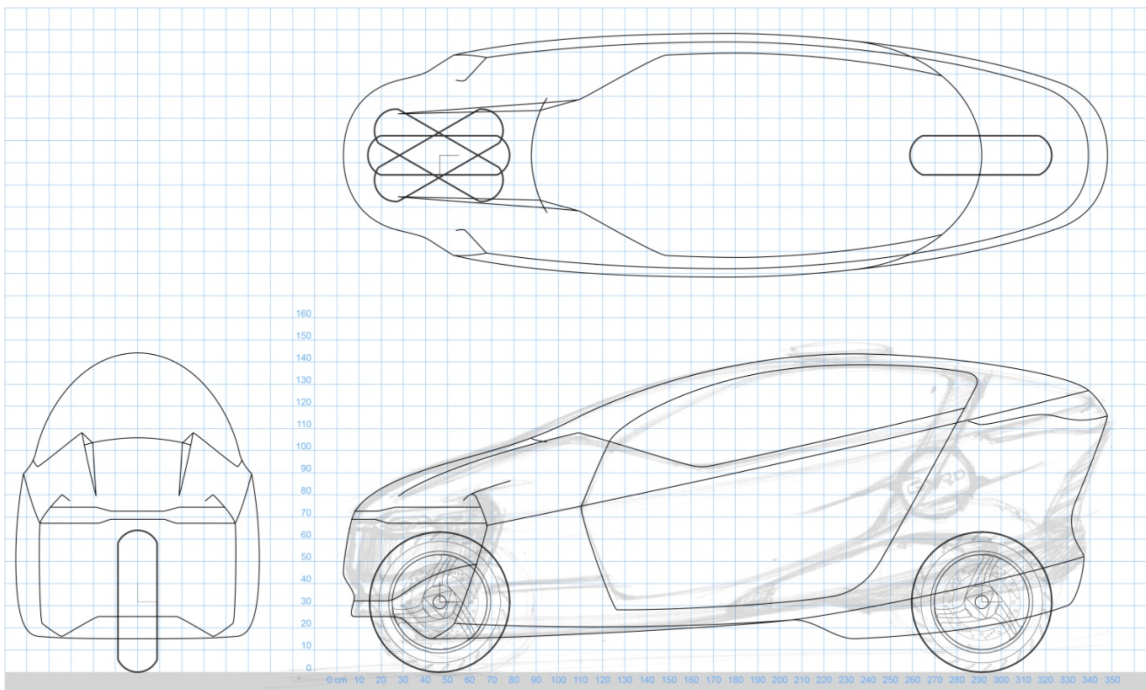
5.2 Package Layout Design of RapiDES

Once the design direction has been nailed down, the Concept Exploration phase concludes and is followed by the Package Layout Design phase. According to Macey & Wardle, packaging in vehicle design refers to "all of the elements in the vehicle architecture that are driven by function, not style."[71] It is the placement of the occupants

[71] Macey, Stuart, and Geoff Wardle. *H-Point, The Fundamentals of Car Design & Packaging.* Pasadena: Art Center College of Design, 2008: 221.

and the main components in relation to the volume and proportion of the vehicle. The final sketch of RapiDES is used as an underlay upon which the definitive design line work is laid, as shown in Figure 5.7.

Figure 5.7. Final sketch used as underlay.



As mentioned in the design requirements of RapiDES that it is able to carry two 95th percentile male adults (about 1.9 m tall). This requirement is being ensured in this phase where these two 95th percentile male manikins are being carefully enveloped in the package as shown in Figure 5.8.

Figure 5.9 shows the main component layout of the design. These are:

- Hub motors mounted in the front and rear wheels
- Electronics above the front wheel and behind the instrument panel
- Gyroscopes underneath the rear seat
- Battery pack behind the rear seat

Figure 5.8. Two 95th percentile males contained in RapiDES.

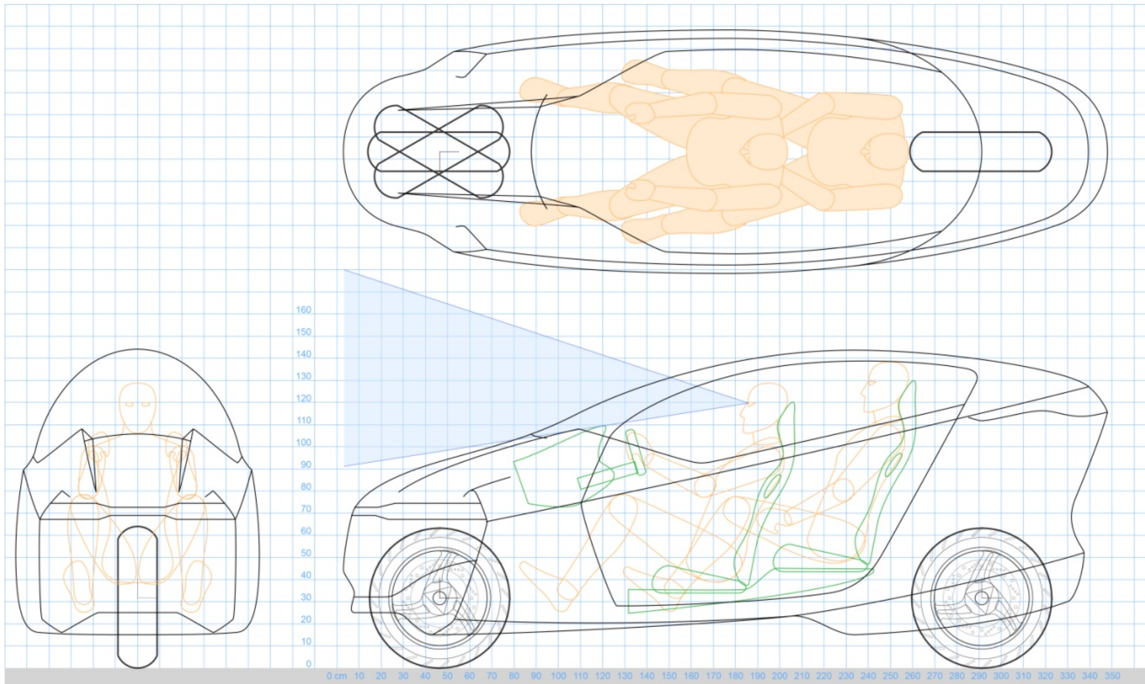
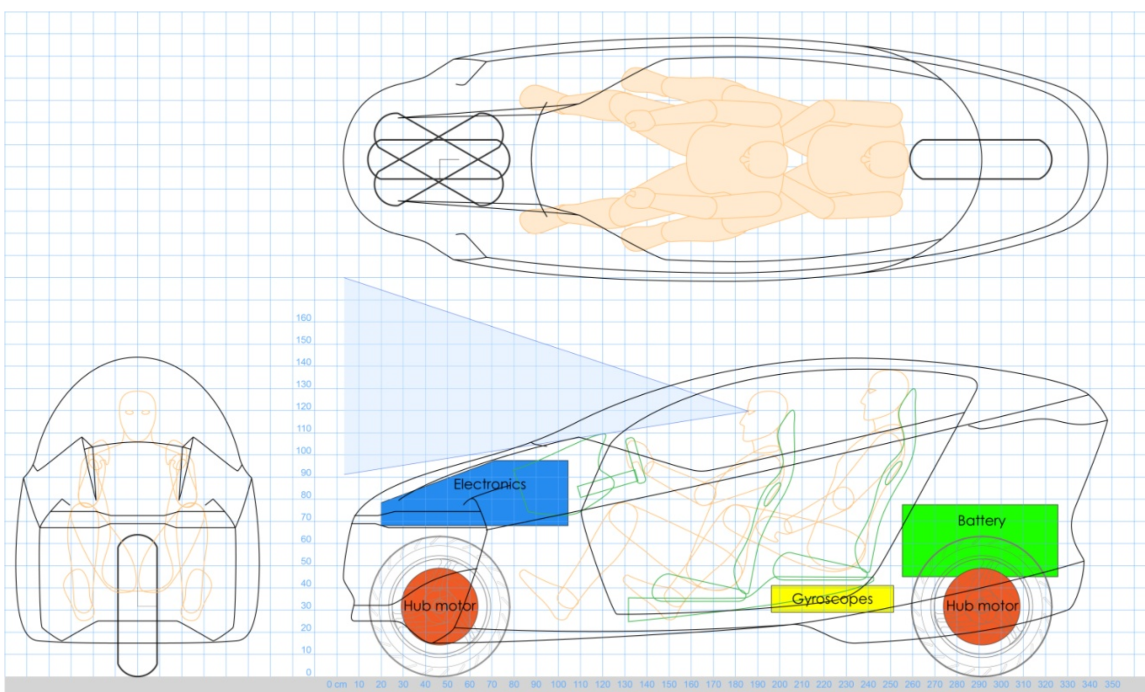


Figure 5.9. Main component layout of RapiDES.



As can be seen in Figure 5.9, the design can carry two 95th percentile males and minus the space for main components, there is still plenty of space for equipment storage for each different emergency service. For the fire rescue version which is a single-seater, the rear seat will be replaced with a light weight aerial ladder.

Actually this process of package layout design was not done in a linear path as presented above. The process went back and forth, juggling between the design curve lines, seating placement of the manikins, and constantly adjusting the size and placement of the final sketch to suit the design. The final design line work and the optimum package layout design were achieved after many attempts of fine tuning.

5.3 3D Modeling & 3D Printing

Having fixed the design line work for the side view, the top view and the front view in Package Layout Design phase, these views can then be imported into a computer aided design (CAD) programme to be used as references for 3D modeling of the design. These orthographic views are oriented to their respective planes and scaled to the full scale of the model, as shown in Figure 5.10.

The CAD programme used here is Creo, formerly known as Pro-Engineer and Wildfire. In the past Pro-Engineer was notable for being a CAD programme for the engineers but not for the designers. However over many iterations of the programme which has become what is known as Creo today, it has had many “designer friendly” features to aid in the creativity process of designing. Among the most important of such features is the “Freestyle” feature, which is essentially a sub-divisional surface modeling method used mostly in gaming and entertainment industry. The integration of “Freestyle” feature in an engineering CAD programme is a welcoming feature that will increase the flexibility of modeling, without having to define too many reference datum as before. The process starts with a primitive sphere, and then it is pulled, extruded, and sub-divided, much like

Figure 5.10. Orthographic views of design line work oriented in CAD.

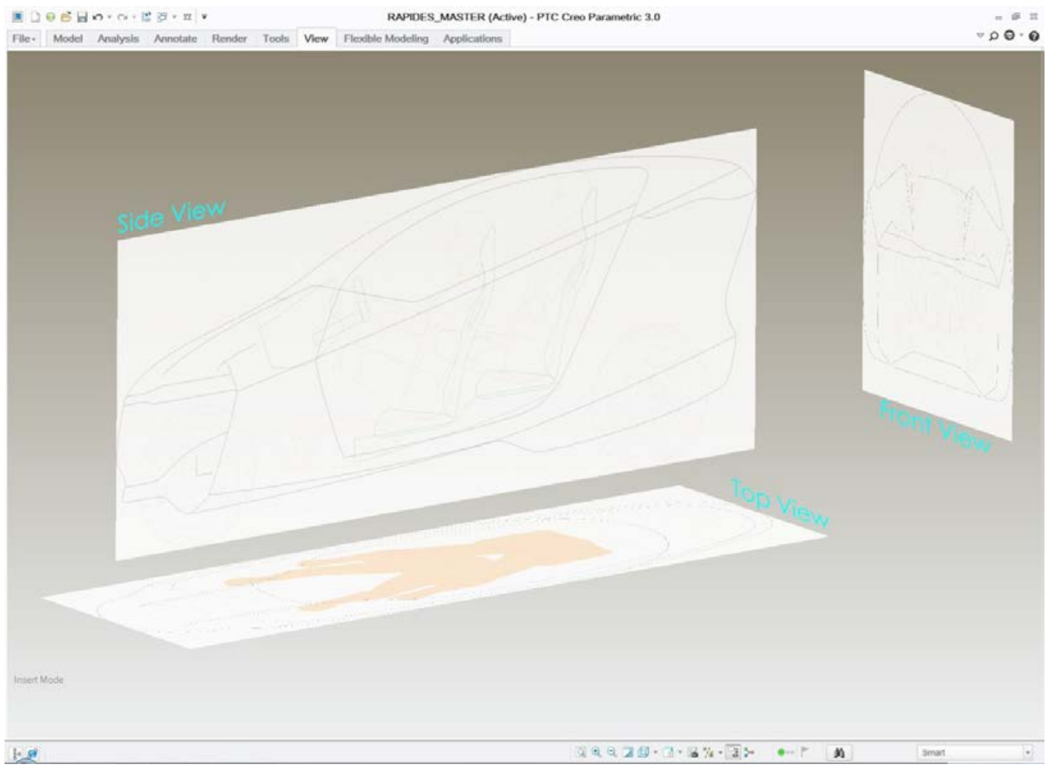
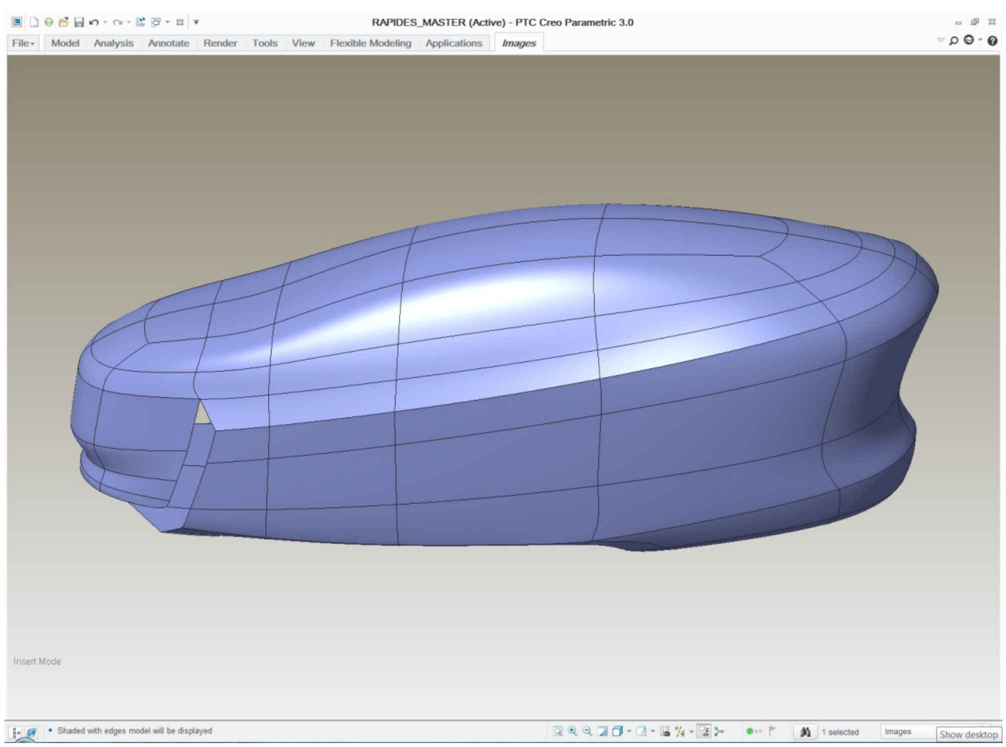
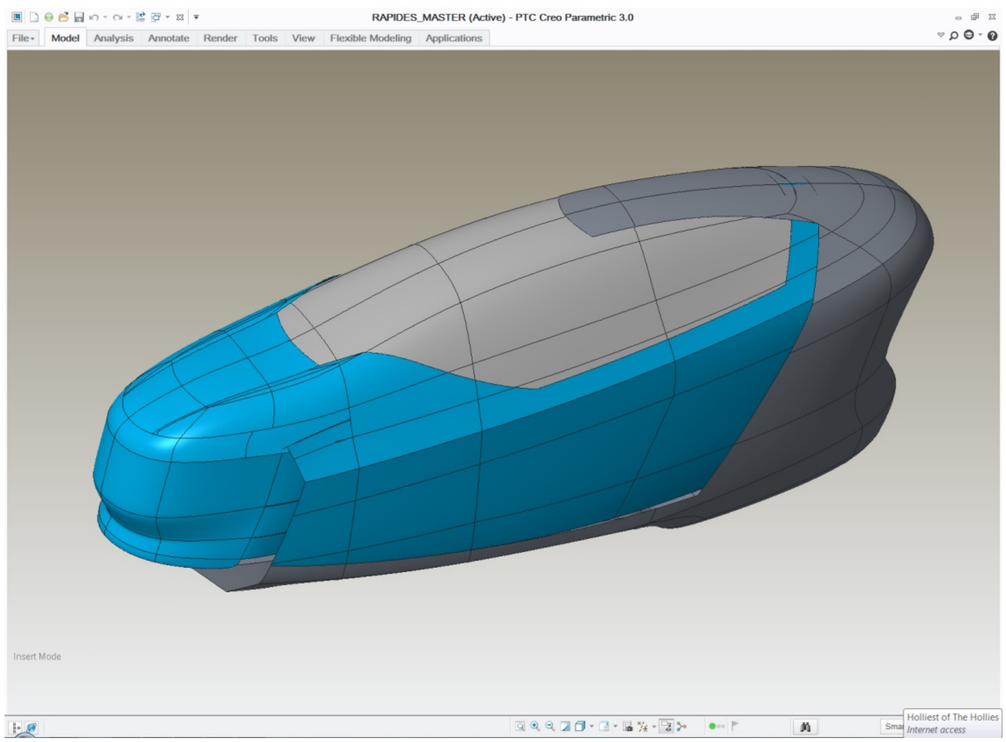


Figure 5.11. Digital sculpting done with "Freestyle".



sculpting with clay, except that I have more control and less messy. Figure 5.11 shows the result of digital sculpting that is of very high surface quality and very close to the design intention for RapiDES.

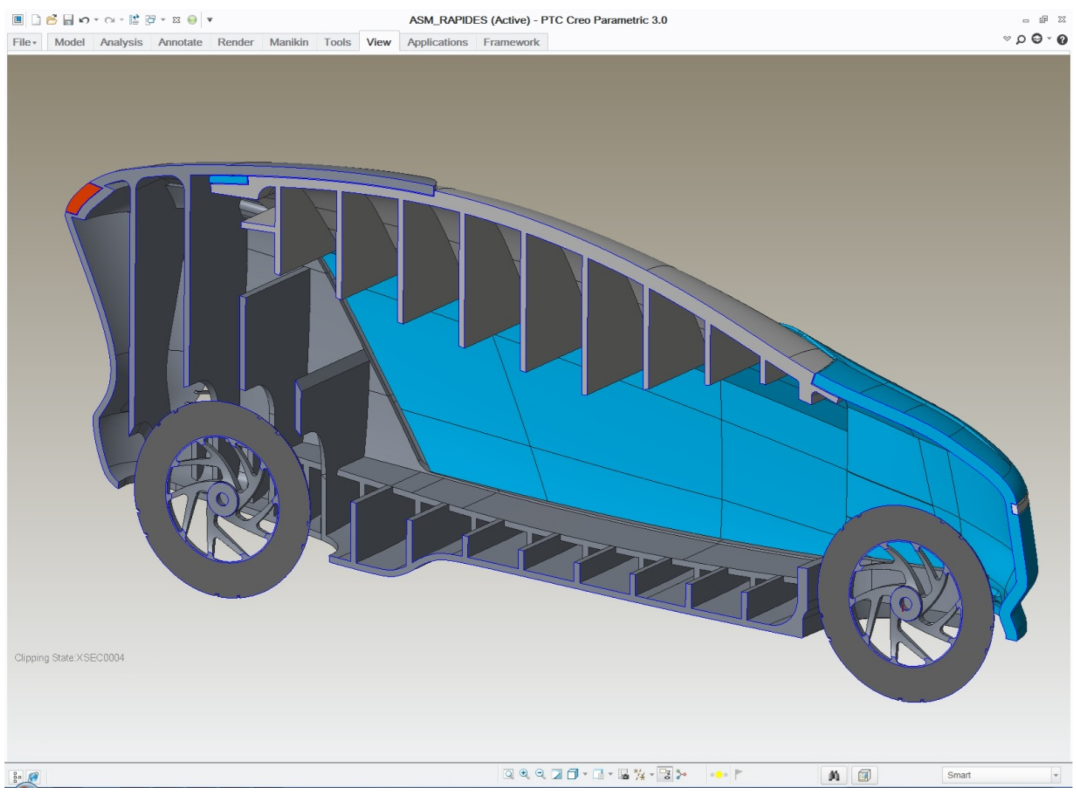
Figure 5.12. Base surface multiplied and trimmed to create surfaces for different parts.



After obtaining this base surface using “Freestyle” feature, more detailed design can be added on using conventional surface modeling technique of creating construction curve and surface. For example, the design feature in front of the windshield as shown in Figure 5.12 which is not there in Figure 5.11, will be difficult to achieve in “Freestyle” but with the “Freestyle” surface as the base, subsequent surface will be easier to build upon. Also, the “Freestyle” surface is also copied and pasted several times, and then trimmed to different surfaces for the body (light blue), the greenhouse (light grey), and the underbody (dark grey).

For the purpose of 3D printing, the model needs to have wall thickness and structural strength in order to be able to print successfully. Therefore the next stage of modeling work is to split the master model into different parts and then create wall thickness and build structural support features for each part. The way these different parts will be assembled is also considered. Figure 5.13 shows the sectional view of the assembled parts with structural support features.

Figure 5.13. Sectional view of the assembled parts.



The finished 3D model was sent to a 3D printing service company in the U.S., Shapeway, and just one week later the printed parts were delivered to me. Figure 5.14 shows the 3D printed parts assembled together.

Figure 5.14. Assembled 3D printed model of RapiDES.

5.4 Detail Modeling

The CAD modeling for 3D printing is complete, but the design is not complete without interior features such as the instrument panels, the steering, and the seats. Also the doors and the attached windows need to be separated from the body in order to open to reveal the interior of the vehicle for rendering.

Figure 5.15 shows the details of the 3D modeling of the steering wheel. Even though this part will not be made into 3D printed part, attentions and considerations have been paid to ensure the ergonomics of the handling is good. Same thing happens to the seat design as shown in Figure 5.16. For the modeling of these two parts, again the “Freeform” feature comes in handy which is very well suited for modeling organic form.

Figure 35. Ergonomic design of steering.

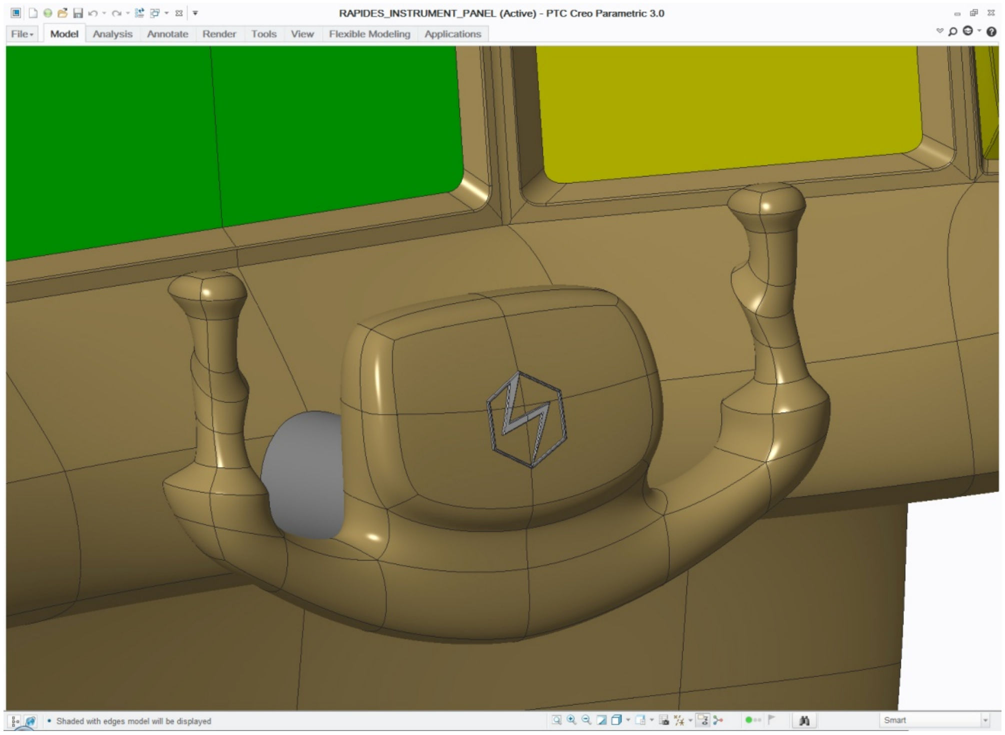
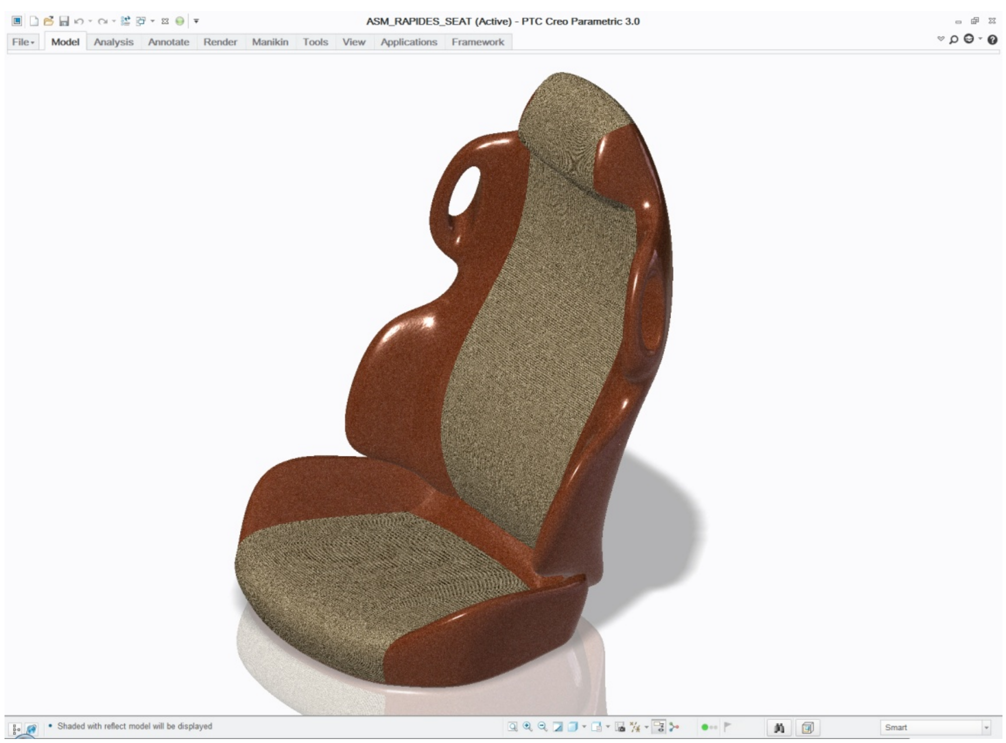


Figure 36. Seat design of RapiDES.



5.5 Summary

In this chapter, the design process starts with first defining the keywords for design direction, and second collaging relevant images based on these keywords as inspiration board. Based on the inspiration board, concept exploration sketches are generated and final design is nailed down for package layout design. Definitive design line work is made to encompass two 95th percentile males and the main components. The orthographic views are brought into CAD programme as references for modeling. The CAD model is prepared for 3D printing and rendering. In the next chapter, we will be evaluating the design with the help of 3D renderings.

CHAPTER 6: DESIGN EVALUATION

In this chapter, the design of RapiDES comes under close scrutiny, with the help of 3D renderings. As stated in the beginning of this thesis, the only means of evaluating the success of this project will be done through the design, which is reflected in the 3D renderings of the design of RapiDES in context of the environments and requirements as entailed in the scenario studies.

6.1 Evaluation of the Design

As has been mentioned in the introductory chapter, the only way to evaluate the success of this thesis/project is through the design of RapiDES, since a full size working prototype is not technically and financially feasible for this project. Having said that, effort was made in order to present the full scale side view rendering of the design in the form of 2x3 tiles of printed panels on the wall of Fine Art Building (FAB) Gallery during the Make Good Graduate Show (running from August 25 to September 19, 2015), as shown in Figure 6.1. Together with the scaled down 3D printed model, this display of work presents the spectators a good idea of the size of the vehicle and detailed design of the vehicle. This way of presentation is also commonly used in the automotive industry to evaluate and validate a design during the early stage of design development.

And the best way to evaluate the design at this stage is through the renderings of the vehicle in the context of its environment and the tasks it performs. The most important essence of RapiDES is its narrow body width that allows it to make its way through heavy traffic during rush hour. In Figure 6.2, a RapiDES can be seen performing lane splitting through the sea of cars, which would be impossible for conventional emergency services vehicles. In Figure 6.3, a RapiDES emerges from the congested traffic of downtown Manhattan in New York City, leaving its bulkier counterpart behind in the congestion.

Figure 6.1. Full scale side view rendering of RapiDES.

Figure 6.2. A RapiDES performing lane splitting.

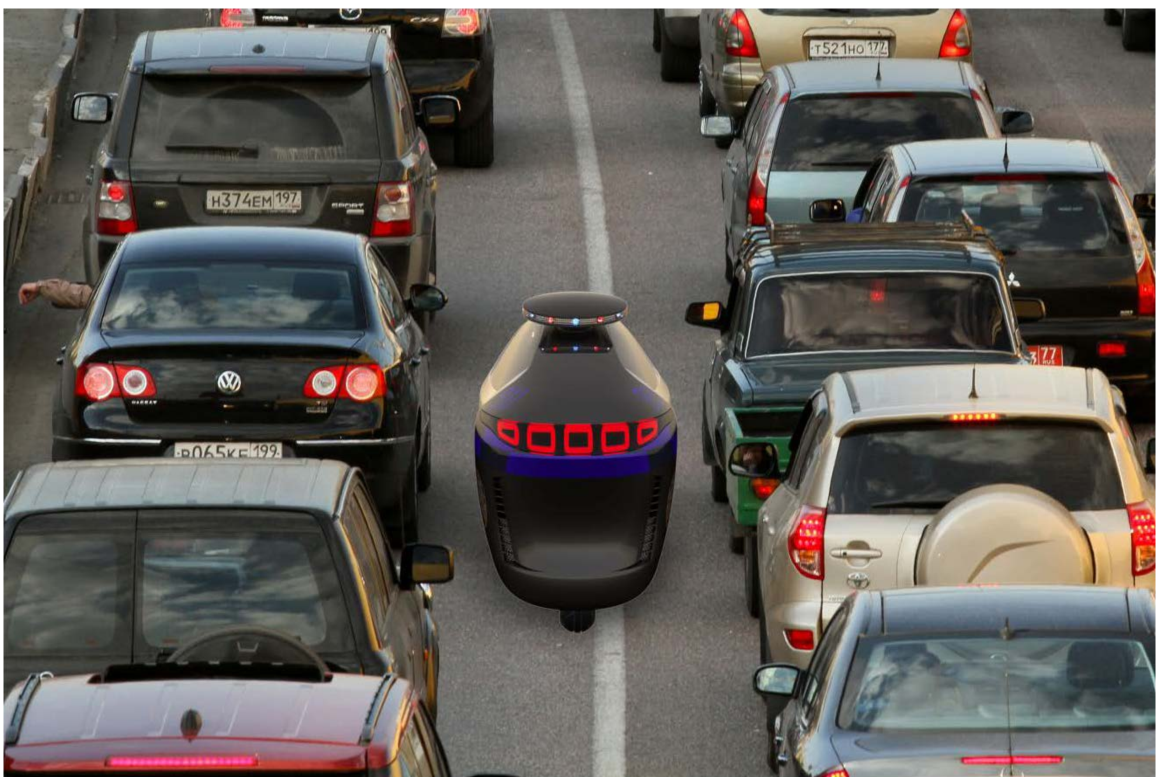


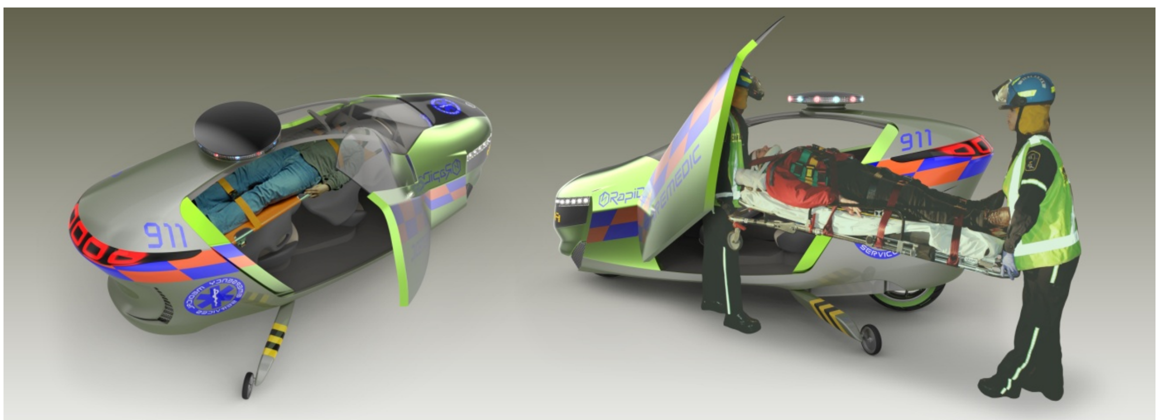
Figure 6.3. A RapiDES emerges from the congested traffic of New York City.

Figure 6.4. A RapiDES travelling in the snow.

Another important feature of RapiDES is its all-weather capability. In Figure 6.4, a RapiDES is seen travelling when it is snowing, which would not be possible for the mounted policemen on motorbikes.

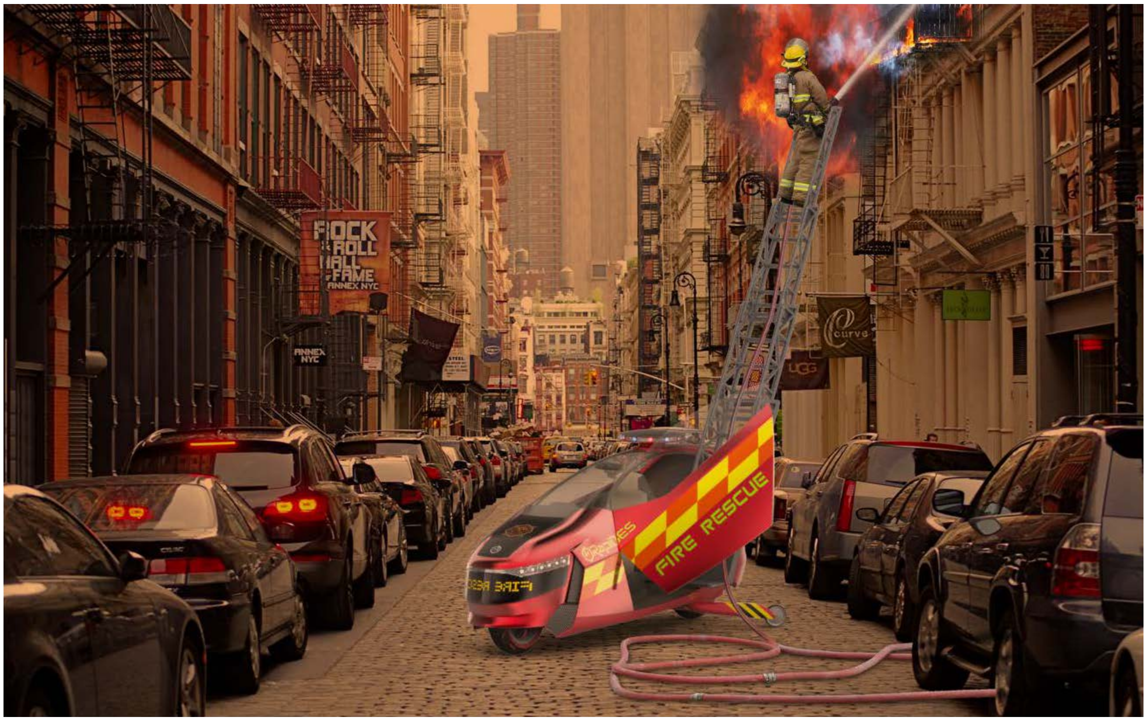
As described in the scenario for EMS, RapiDES for EMS is capable of carrying a patient lying in a stretcher and travelling to the hospital in auto-pilot mode. This scenario is shown in Figure 6.5, where a patient is being loaded and after the patient has been loaded into a RapiDES.

Figure 6.5. Patient loaded and being loaded into RapiDES.



In the scenario of fire rescue, the fire rescue version of RapiDES has a light aerial ladder that the firefighter can utilize to provide an elevated stream using the on-board impulse fire extinguishing system (IFEX), to make the fire suppression more efficient, as shown in Figure 6.6.

Figure 6.6. A Fire Rescue RapiDES and firefighter suppressing fire.



6.2 Summary

In this chapter, the common way of evaluating design proposals at an early stage of vehicle design project in the industry is being used to evaluate the design of RapiDES. As can be seen in these renderings in context that simulate the environments and the tasks these RapiDES will be performing, I am confident to conclude that the project of designing a Rapid Deployment Emergency Services (RapiDES) vehicle is successful and worthy of passing the evaluation of initial stage of a real vehicle design project.

CHAPTER 7: FUTURE WORK & CONCLUSIONS

In this chapter, the works that are left untouched of this thesis/project will be looked at and potential areas of further development will be discussed. This thesis/project will then be concluded with a quick recap of the works and findings that have been achieved. One important criterion to measure the success of this thesis/project is to view it as an initial stage and feasibility study of a design proposal for a vehicle design project in automotive industry. It is to this extent that the design of RapiDES can be evaluated fairly and objectively.

7.1 Future Work

The work done so far has been focusing on the industrial design aspect of vehicle design. The area which has not been touched on but could be a potential graduate level project by itself is the User Interaction design of the vehicle control system. This system not only deals with the graphical user interface design of the various display screens on board, but also deals with various physical control knobs and switches of the vehicle.

The other important aspect of the vehicle design which is left untouched in this thesis/project is the engineering aspect of the vehicle, of which the mechanics of gyroscopic stabilization and its integration with the microelectronics is the most important. Even though the concept and prototypes of gyro-stabilized vehicles have been around for a century, but the advent in microelectronics in recent years would offer a new way of making the mechanism work more smartly and efficiently. Again, this is another graduate level or doctorate level engineering topic to be tackled. I sincerely hope that my works shown in FAB Gallery would be seen by some engineering students and spark their interest in this field of research, and that the project could continue in University of Alberta to develop into a full-sized working prototype of the design.

Another future work for this project is the accompanying consumer version of RapiDES, Rapido, which should be taken as an integral part of the effort of reducing traffic congestion, improving the environment, and ultimately reducing the emergency response time. Scaling down the size of emergency services vehicles alone will improve the emergency response time up to a certain level, but it is only like walking one legged. However, if there are more car drivers converting to Rapido, the traffic will become even smoother and RapiDES will have even better performance in emergency response time. Figure 7.1 shows a Rapido, which is essentially a RapiDES minus the features of emergency services.

Figure 7.1. Rapido the civilian version.

7.2 Conclusions

This thesis/project starts with a quest of establishing a case that justifies the need for a new solution to improve the response times of various emergency services. The case is established with the findings of how critical the quick response times are to the survival of patients, to the safety of property in fire, and to the success of crime crackdown.

The core essence of this thesis/project is the novel proposition that the size of conventional emergency services vehicles is itself a major part of the obstacle to quick response times. Therefore, the logical suggestion of improving the emergency response time is to switch to smaller, smarter, and more responsive units that may not replace the big brothers at all, but rather serve as the pioneers of emergency services.

This study then uses the methods of research mapping and scenario study exercise to figure out the best solution to the problem and generate a series of design requirements that serve as the foundation for the design activity of RapiDES. A brief history and current development of gyro-stabilized vehicles is also examined to provide a good background understanding of such vehicles. The subsequent design process is rather straightforward with the well founded groundwork.

The outcome of the project is a design of Rapid Deployment Emergency Services (RapiDES) vehicle that fulfils the requirements as outlined in the design brief and serves as the baseline design for variation models that suit the needs and contexts of different market. If the work done is seen as the initial stage or preliminary study of a real vehicle design project, the outcome of the design is deemed successful. RapiDES are shown to perform various tasks in environments as described in the scenario study exercise in the 3D renderings. A scaled down model is displayed together with the full size side view rendering on the wall at FAB Gallery during the Make Good Graduate Show, allowing spectators to examine the quality of the design, which is a common industry practice of reviewing automotive design at preliminary stage.

However, the project is far from complete and as mentioned in previous section, the User Interaction aspect and the working mechanics of gyroscopic stabilization are worthy of respectful graduate and doctorate level research. Nevertheless, it is hoped that the work done up to this stage is good enough to serve as a catalyst to spark more interest both in academia and corporation that a fully working prototype of RapiDES will one day see the light of day. And may I reiterate, “RapiDES will be to the police patrolling in car what Segway is to the police patrolling on feet.”

GLOSSARY

CAD. Computer aided design.

EMS. Emergency medical services.

Emergency response time. In general, it is a measurement of time taken for the first responder to reach the scene of emergency from the moment emergency call is received. In actual fact, different departments from different jurisdictions define emergency response time differently.

Emergency services. Refer to the emergency medical services (EMS), fire department, and police department.

Flashover. The point when all combustibles in the space have been heated to their ignition temperature and spontaneous combustion occurs.

ICE. Internal combustion engine.

IFEX. Impulse fire extinguishing system.

Package. Packaging in vehicle design refers to all of the elements in the vehicle architecture that are driven by function, not style. It is the placement of the occupants and the main components in relation to the volume and proportion of the vehicle.

RapiDES. Rapid Deployment Emergency Services.

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APPENDIX A: Design Brief of RapiDES

Problem Statement

In many big cities in the North America, traffic congestion has critically impacted the emergency response time which may affect the safety of lives and properties of people. While many suggestions have been proposed to reduce the emergency response times, none of them have addressed the fact that the size of conventional emergency services vehicles such as the jumbo-sized ambulances and the mammoth-sized fire engines, is itself a major obstacle to reduce the emergency response times. Therefore, it is imperative for a solution of a new vehicle design to reduce the emergency response times of various emergency services and to reach the scene of emergency safe and dry, and that it is also well equipped to do the job.

Objective

As an initialization stage and feasibility study of a new vehicle design for emergency services in the North America, create a design proposal for the Rapid Deployment Emergency Services (RapiDES) vehicle, which can be customized to suit the needs of different emergency services of emergency medical service, fire rescue, and law enforcement.

Key Issues

In order to weave through heavy traffic easily, RapiDES needs to have a narrow frontal profile, which is a narrow body width. The narrowest possible frontal profile is achievable through the inline two-wheel configuration layout like that of a motorcycle. Mono-wheel configuration has been excluded for practicality reasons. However a motorcycle does not provide protection against collision and shield the occupants from the elements. Therefore an enclosure is needed. But an enclosed inline two-wheel vehicle has problem in balancing in slow speed and stationary because the operator cannot balance the vehicle with his/her feet like when riding a motorcycle. Thus some self-balancing capability is needed with the help of gyroscopes.

Gyroscopically balanced vehicles tend to become too stable, and might experience difficulty in handling agility such as turning or changing direction in high speed. To overcome this problem, one possible solution is to employ all-wheel-steer technology which is more complicated mechanically in transmission design with internal combustion engine (ICE). The other solution is to employ two gyroscopes in the vehicle for the balancing act, and with the help of various on-board sensors and computer to adjust the precession angles of the two gyroscopes so that they create slight imbalance in one direction that is in accordant to the operator's turning intention. These two solutions can be combined to improve the overall handling agility of RapiDES.

In addition, the requirement for all-weather operation calls for the need of all-wheel-drive feature to help in the manoeuvrability in snow condition. This feature is also more complicated mechanically with internal combustion engine, like the all-wheel-steer feature is. However, if the vehicle employs two electric motors that are mounted directly in the front and rear wheel hubs, the mechanical design for both all-wheel-steer and all-wheel-drive will be much simpler. The choice of electric motor over internal combustion engine is also in compliant with the environmental requirement which will have more stringent emissions law in the future. This greener choice will help RapiDES gets more acceptance from various stakeholders such as the public and the authorities.

Key Features & Design Requirements of RapiDES

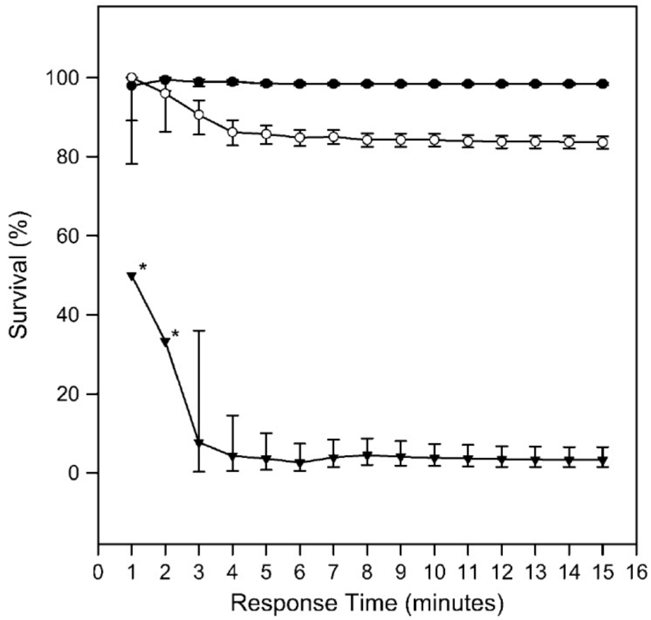
- RapiDES is a narrow-bodied inline two-wheel vehicle, fully enclosed for weather and safety protection with gyroscopic self-balancing capability that will keep it from tipping over when the vehicle is travelling in low speed or stationary.

- RapiDES has a pair of retractable side wheels (landing gears) to support the vehicle when it is parked. These landing gears also expand side ways to improve stability in the scenario of RapiDES being used as a fire rescue unit.
- RapiDES can carry up to two 95th percentile males in basic configuration.
- RapiDES is an electric powered vehicle, with two powerful electric motors mounted in both the front and rear wheel hub.
- The gyroscopic stabilization effect is created by a pair of spinning flywheels. These flywheels are also part of the energy storage system together with high capacity battery pack and Kinetic Energy Recovery System (KERS) that improves the vehicle's efficiency.
- These flywheels, sealed in vacuum enclosure to reduce friction, are built with light weight alloy material and are hollow with channels. When they first start spinning, they pick up speed fast due to the hollow construction and light weight material. These hollow channels are then gradually filled with heavy hydraulic fluid as the flywheels pick up speed. This method will reduce the waste of energy to spin the solid and heavy flywheels initially (a novel idea).
- RapiDES is an all-wheel-drive vehicle that can battle the tough weather condition in the northern territories.
- RapiDES is an all-wheel-steer vehicle. Couple this with the computer- controlled gyroscopic balancing system that creates imbalance and makes it better in negotiating corners and bends better than conventional gyroscopically stabilized vehicles.
- RapiDES is equipped with many state-of-the-art safety features such as sensors, cameras, airbag, ABS, and proactive anti collision system.
- RapiDES can be driven in manual mode or auto-pilot mode.
- RapiDES can be configured for different needs of various emergency services.

APPENDIX B: Top 30 Vehicle Density by State in the United States In 2003

Rank	State	Total Vehicles	Land Area (km^2)	Density (Unit/
1	Dist. of Columbia	228,351	158	1,445.259
2	New Jersey	6,711,601	19,047	352.371
3	Rhode Island	805,740	2,678	300.874
4	Massachusetts	5,479,394	20,202	271.230
5	Connecticut	2,963,540	12,542	236.289
6	Maryland	3,876,610	25,142	154.189
7	Delaware	686,817	5,047	136.084
8	Florida	14,526,125	138,887	104.590
9	Ohio	10,536,372	105,829	99.560
10	New York	10,801,701	122,057	88.497
11	Pennsylvania	9,724,453	115,883	83.916
12	California	30,248,069	403,466	74.971
13	Illinois	9,250,014	143,793	64.329
14	Virginia	6,346,009	102,279	62.046
15	Indiana	5,739,348	92,789	61.854
16	Michigan	8,540,325	146,435	58.322
17	Hawaii	902,910	16,635	54.278
18	Georgia	7,730,300	148,959	51.895
19	New Hampshire	1,144,963	23,187	49.380
20	North Carolina	6,118,644	125,920	48.592
21	Tennessee	4,795,676	106,798	44.904
22	South Carolina	3,161,894	77,857	40.612
23	Louisiana	3,713,561	111,898	33.187
24	Kentucky	3,388,879	102,269	33.137
25	Wisconsin	4,647,150	140,268	33.131
26	Alabama	4,329,245	131,171	33.005
27	Washington	5,378,891	172,119	31.251
28	Missouri	4,459,872	178,040	25.050
29	Iowa	3,368,915	144,669	23.287
30	West Virginia	1,408,800	62,259	22.628

APPENDIX C: Percentages of Survival to Hospital Discharge By Paramedic Response Time and Stratified By Risk Groups[72]



Legend

▼High risk group: included all traumatic and non-traumatic cardiac arrest patients.

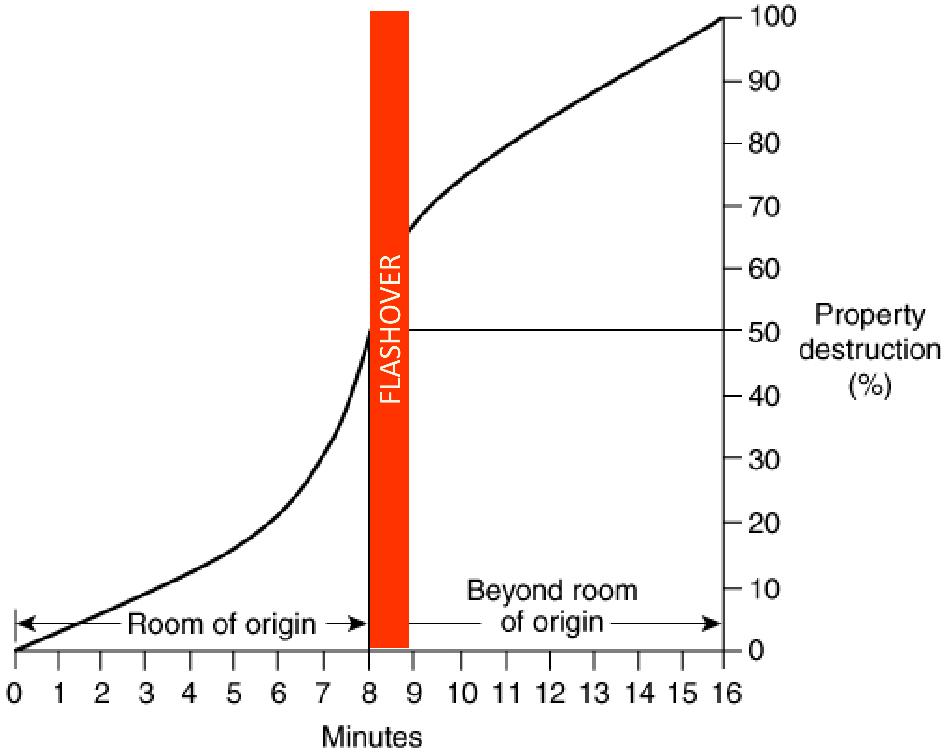
○ Intermediate risk group: included all suicide attempts, accidental exposures, unconscious patients, those with penetrating trauma, those with respiratory complaints, and those who were hypertensive in the out-of-hospital setting.

● Low risk group: all other patients were grouped into the low-risk category.

[72] Pons et al. "Paramedic Response Time: Does It Affect Patient Survival?" 597.

APPENDIX D: Fire Propagation Curve & Flashover Point

(Adapted from: *NFPA 1710,* 17)



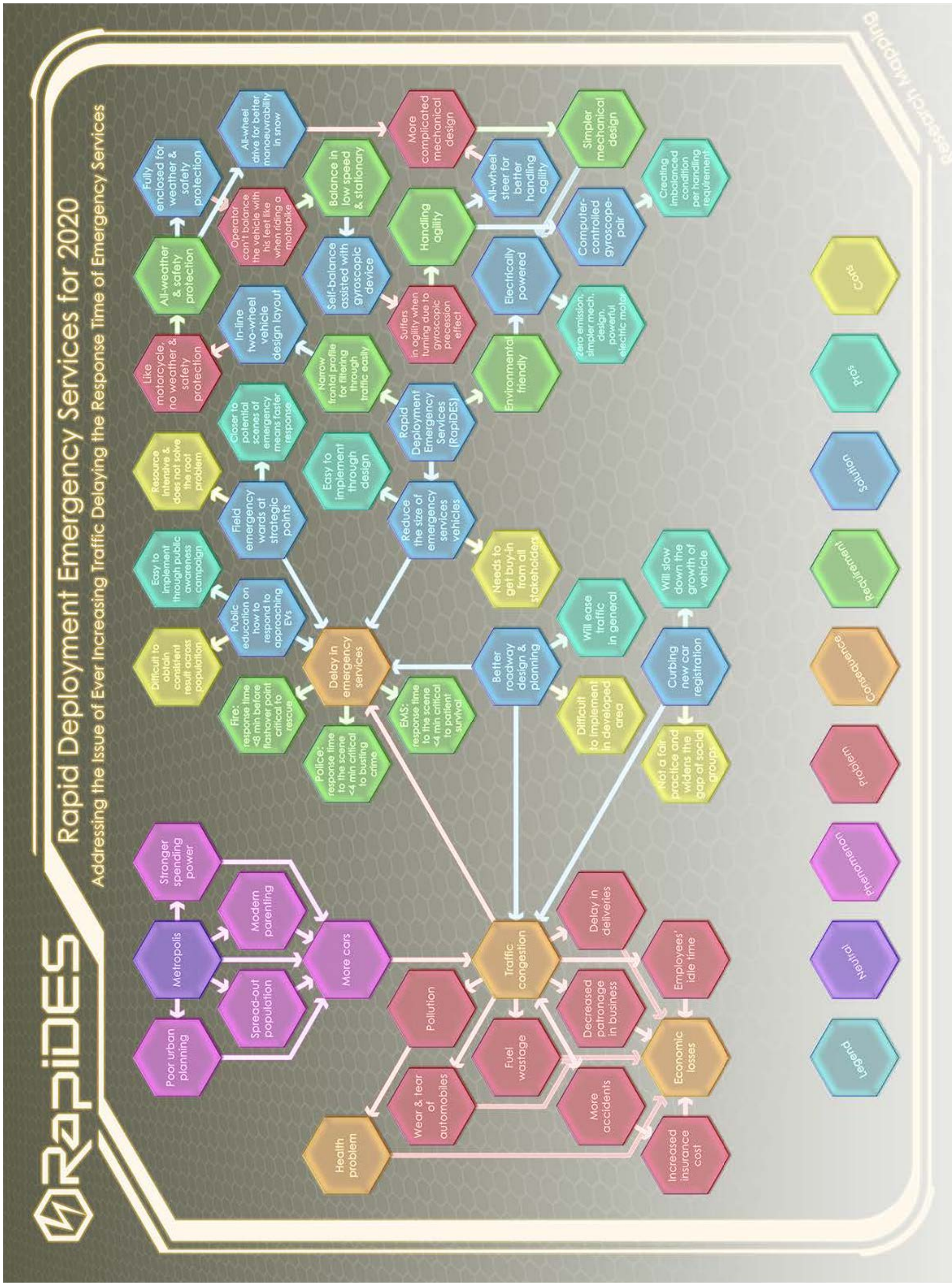
APPENDIX E: Fire Extension in Residential Structures, 1994-1998

(Adapted from: *NFPA 1710,* 17)

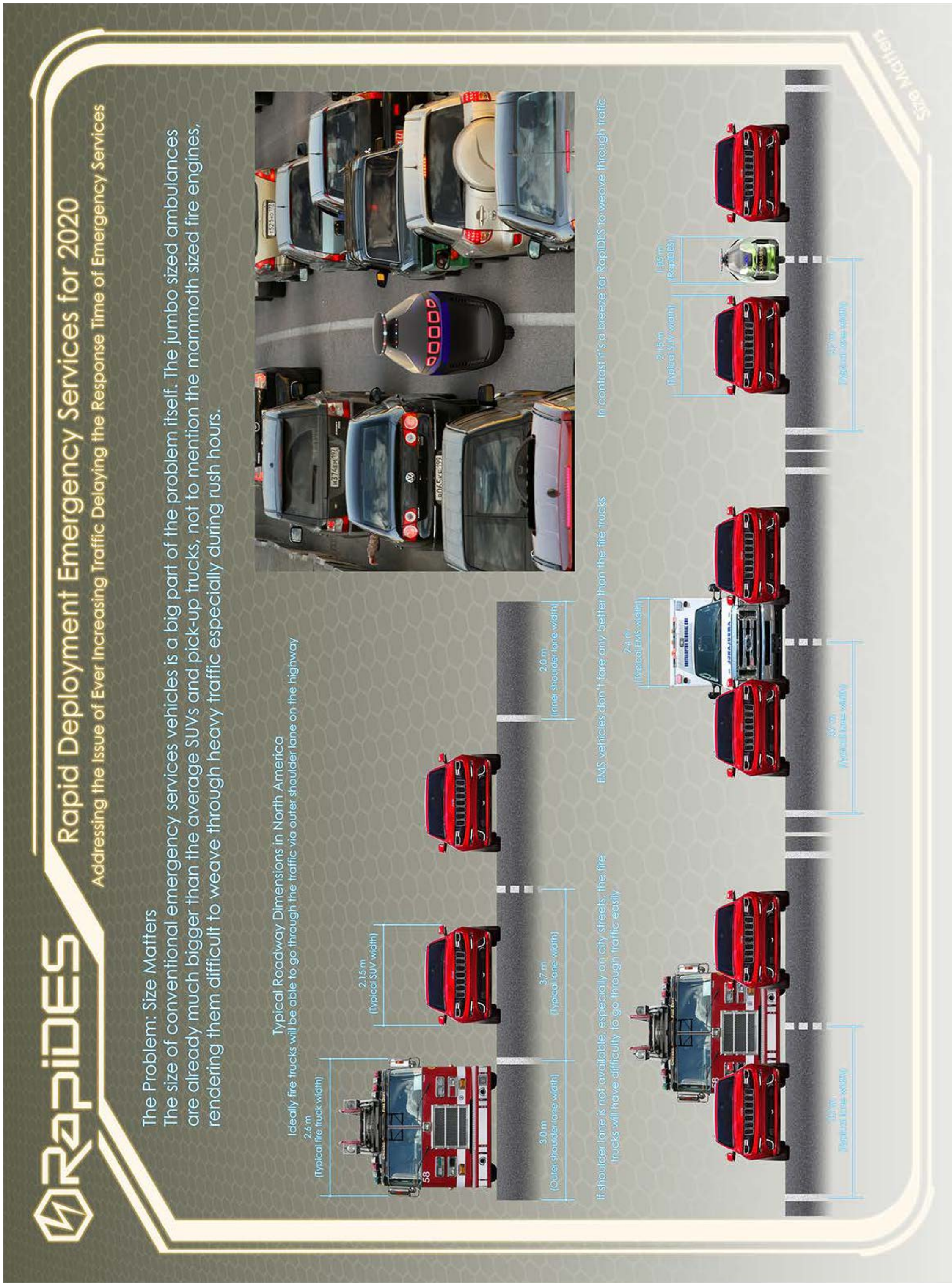
Time (T)	Extension	Rate Per 1000 Fires		Average Dollar Loss Per Fire
		Civilian Deaths	**Civilian Injuries**	
T < 7 min	Confined to room of origin	2.32	35.19	$ 3,185
7 min < T < 10 min	Beyond the room, but confined to floor of origin	19.68	96.86	$ 22,720
T > 10 min	Beyond floor of origin	26.54	63.48	$ 31,912

APPENDIX F: Display Panels for Make Good Graduate Show

F1. Research Mapping



F2. The Problem: Size Matters

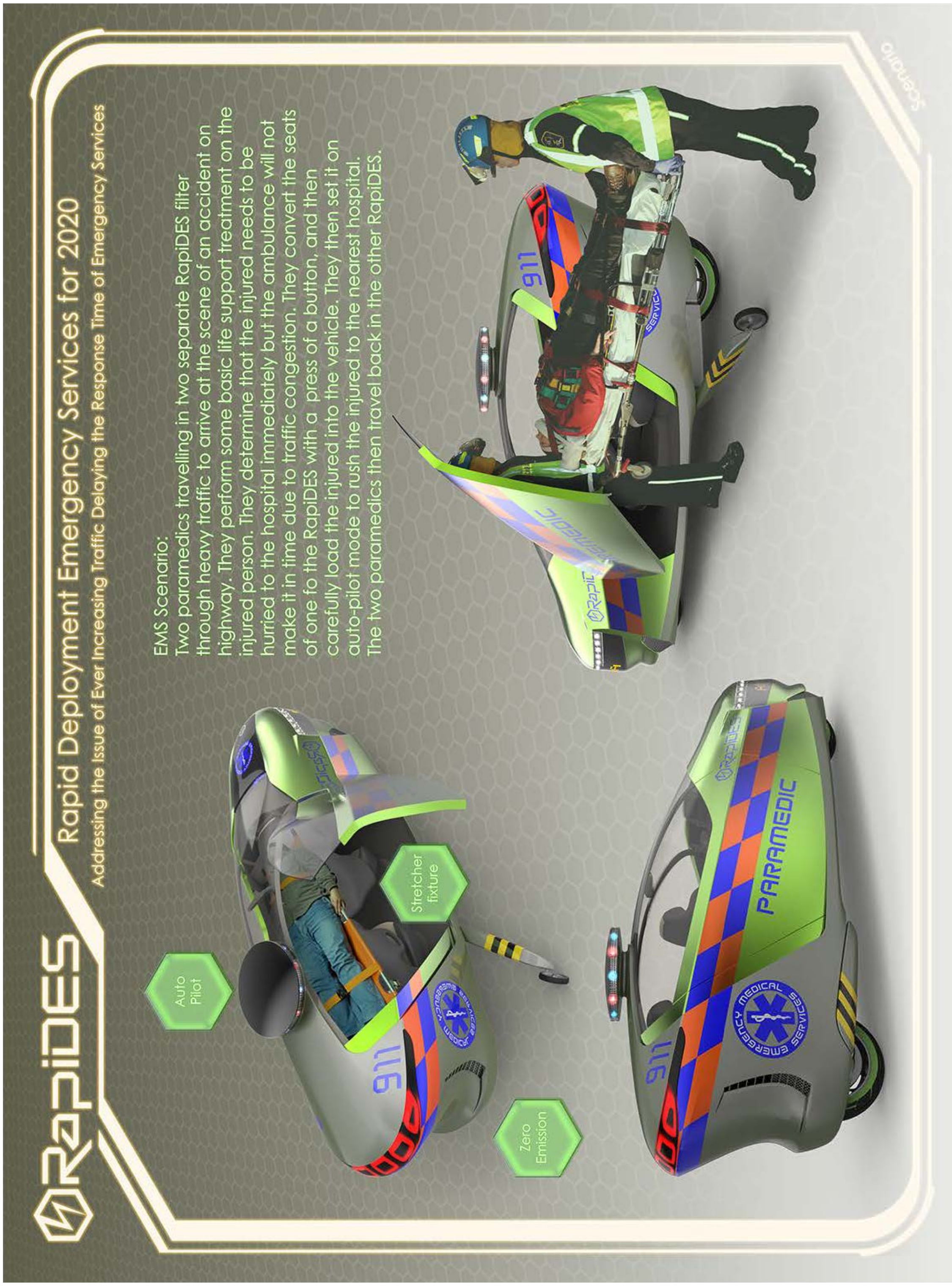


F3. Package Layout Design

F4. Design Development

F5. Vital Statistics

F6. EMS Scenario



F7. Law Enforcement Scenario

F8. Fire Rescue Scenario