A System Dynamics Model of Automotive Recycling in Australia

Ezzat El Halabi

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A thesis submitted for the degree of Doctor of Philosophy of the Australian National University

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To mom and dad, Raja and Mohammad Fayez
Declaration

The work in this thesis is my own except where otherwise stated. The work was undertaken between August 2007 and January 2018 at the Australian National University, Canberra. It has not been submitted in whole or in part for any other degree or qualification. Some of the materials presented in these chapters were published as peer-reviewed papers. However, for clarity and consistency, some parts of the materials were revised, removed or extended to enhance the presentation of this thesis.

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This work would not have been possible without the support of my family. My dad instilled in me his passion for cars. While mom, a meticulous homemaker, inspired the desire for perfection and care for the environment. My wife and best friend Maha, whose patience, care and support helped me through the darkest hours. And my daughter Mai, born while producing this thesis, whose smiles lifted my morale in the last stretch.
Abstract

Automotive or End of Life Vehicle (ELV) recycling in Australia is a profit-driven activity undertaken by automotive dismantlers without the oversight of explicit government policy. Among the growing concerns are the environmental impact of the activity and the failure of the industry to implement a voluntary code of practice. An underlying problem clouding these concerns is the literature gaps concerning the operations of the industry, the issues facing the industry, and how these issues could be overcome. This research reports on a series of studies undertaken to address these knowledge gaps by applying System Dynamics (SD) as an investigative approach.

Semi-structured stakeholder interviews are conducted to gather quantitative and qualitative data about business operations and material flows. An adapted Qualitative Data Analysis method is used to extract the essential variables and causal links thematically. An aerial survey of recyclers premises and two ELV dismantling trials are also conducted to collect data for variables in the simulation SD model. Furthermore, a Scenarios Planning workshop, including two print surveys, is facilitated to validate the scoping of the problem and model areas and to determine plausible scenarios facing the industry and their effects.

This research identifies the sustainability of the industry as an overarching problem, with the financial performance affecting and determined by five areas of concern: i) ELV supply/demand and disposal, ii) workforce, iii) premises, iv) parts sales, and v) industry image.

The research also identifies two major growing threats to the industry. The first threat is an increasing unfair competition from backyarders at the ELV supply level. This issue is weakening the industry financial performance and overall industry image while increasing the overall environmental impact of the dismantling activity. The second threat lies with the automobile increasingly becoming a throw-away product, catalysed by the motorists and insurance industry preference for new instead of used parts for repairs. This growing trend threatens the
demand for parts reuse and the business case for the industry.

The simulation results support a nationally harmonised and enforced licensing policy with requirements for proper handling of ELVs as leverage to help improve the overall industry image and financial performance, despite the added compliance costs. The policy obliterates the unfair competition by encouraging the backyarders to either fold operations or become licensed operators. The overall environmental impact of automotive dismantling decreases significantly. A longer use cycle for the automobile and the promotion parts reuse could also enhance these metrics further.

A secondary finding is a forward integration business strategy, to help improve the financial performance and reduce the environmental impact, using a multi-dismantling machine to break apart ELVs into broad material categories.
Publications

As part of this doctoral research, the following nine peer-reviewed articles were published:

   Appendix A is the paper as published.

   Section 4.1 is a purposefully modified version of this article.

   Section 3.2 is a purposefully modified version of this article.

   Section 5.1 is a purposefully modified version of this article.

   Section 5.2 is a purposefully modified version of this article.

   Section 3.3 is a purposefully modified version of this article.
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Section 3.4.2 and Section 4.4 are a purposefully modified version of this article.

Section 3.4.3 and Section 4.5 are a purposefully modified version of this article.
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## Terminology

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<tr>
<td>ACT</td>
<td>Australian Capital Territory</td>
</tr>
<tr>
<td>ASR</td>
<td>Automotive Shredder Residue</td>
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<tr>
<td>AUD</td>
<td>Australian Dollars</td>
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<tr>
<td>CLD</td>
<td>Causal Loop Diagram</td>
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<td>ELV</td>
<td>End of Life Vehicle</td>
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<tr>
<td>EOL</td>
<td>End Of Life</td>
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<tr>
<td>GMB</td>
<td>Group Model Building</td>
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<td>GTG</td>
<td>Gate-To-Gate</td>
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<tr>
<td>HCV</td>
<td>Heavy Commercial Vehicle</td>
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<tr>
<td>ICT</td>
<td>Information and Communication Technologies</td>
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<tr>
<td>ID</td>
<td>Influence Diagram</td>
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<tr>
<td>IP</td>
<td>Interactive Planning</td>
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<tr>
<td>LCA</td>
<td>Life Cycle Analysis</td>
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<tr>
<td>LCV</td>
<td>Light Commercial Vehicle</td>
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<tr>
<td>MDM</td>
<td>Multi-Dismantling Machine</td>
</tr>
<tr>
<td>NSW</td>
<td>New South Wales</td>
</tr>
<tr>
<td>NT</td>
<td>Northern Territory</td>
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<tr>
<td>Acronym</td>
<td>Description</td>
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</tr>
<tr>
<td>QLD</td>
<td>Queensland</td>
</tr>
<tr>
<td>PMV</td>
<td>Personal Motor Vehicle</td>
</tr>
<tr>
<td>SA</td>
<td>South Australia</td>
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<tr>
<td>SD</td>
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Chapter 1

Introduction

1.1 Automotive Recycling in Australia

End of Life Vehicle (ELV) management is a critical stage in the reverse life cycle of automobiles. It involves the recovery of reusable parts and segregation of recyclable components and materials for further resource and energy recovery from automobiles which have been deemed uneconomical and unsafe to maintain or use according to the norms or standards of society. A vehicle reaches this stage either suddenly in an accident or gradually due to wear and tear from conditions or years of use.

The Australian automotive recycling industry, consisting of about 800 ELV dismantlers or used parts dealers with around 3400 employees operating as profit-driven enterprises with 1.1 Billion Australian Dollars turnover (IBISWorld, 2011), plays a crucial role in this stage handling about 610,000 ELVs annually or about 4% of the Australian automotive fleet. The industry, turning over, operates with no formal government ELV policies or regulations unlike similar industries in other developed countries (e.g. the European Union countries, Japan, South Korea, Taiwan). In Australia, industry peak body organisations pursued a voluntary code of practice between 1997 and 2007 but with limited success (APRAA, 2010).

1.2 Research Scope

The focus of the study is the Australian industry of automotive recycling. Comparative analyses with other countries, specifically in the literature review, is presented where relevant. It is worth noting that not all operators in the industry view it as a stand-alone sector dedicated for the recycling of ELVs because
their operations include among many, vehicle servicing, mechanical repairs and used car trades. For practical reasons, the study assumes that an automotive recycler or dismantler is an enterprise that generates a significant portion of its revenue (i.e. more than 60 or 80%) from the sale of dismantled parts. This definition tightens the scope and the number of enterprises engaged in the activity to almost half of those estimated.

Concerning historical scope, the modelling carried out relies on information sources up to early 2014 when the research components of this work were completed. The simulation SD model starts from 2003 (due to data scarcity) up until 2023 as the study is limited to mid-term or a decade-long as informed by the stakeholders in a Scenarios Planning workshop conducted in November 2012.

1.3 Literature Gaps

As presented in Chapter 2, based on the history of ELV recycling, the current ELV policy landscape, issues with the policies, and considering the uniqueness of the Australian situation and the relative scarcity of data and information about the Australian ELVs and ELV recycling industry, the following knowledge gaps were identified:
1.4 RESEARCH AIM AND OBJECTIVES

1. Limited information about the operations of Australian ELV recyclers, such as the sourcing of ELVs, processing, disposal, and revenue streams or markets and the influencing factors.

2. Limited information about the Australian ELV recyclers businesses (workforce and premises area size).

3. The impending operational issues and challenges facing the Australian ELV recycling industry.

4. The type of ELV policy that may be effective at addressing the issues without causing significant unintended consequences.

5. The financial and environmental impact of using a multi-dismantling machine for further in-house material segregation of ELVs

Addressing these gaps could help address these key research questions:

1. What are the critical issues facing the Australian ELV recycling industry from a systems perspective?

2. What are the most effective mid-term policies or strategies to overcome these challenges?

3. Could machine-base dismantling serve as a short-term solution to improve the financial and environmental performance of the industry?

1.4 Research Aim and Objectives

The study aims to form a grounded understanding of automotive recycling in Australia and explore the challenges and scenarios facing it from a systems-based method. More specifically, the research objectives are:

1. To explore the current operational processes in the Australian automotive recycling industry and identify the issues and challenges.

2. To analyse the most impending issues and challenges facing the Australian automotive recycling industry through qualitative and quantitative System Dynamics modelling.

3. To identify key scenarios facing the Australian automotive recycling industry in the coming decade.
4. To study the effects of the scenarios on the Australian automotive recycling industry using the baseline models.

5. To propose a policy or a strategy that improves the financial sustainability and reduces the environmental impact of the Australian automotive recycling industry.

1.5 Research Approach

This investigative and inductive study (Maxwell, 2004) tackles a limited body of knowledge about the Australian automotive recycling industry and relies on qualitative and quantitative data analysis to develop simulation models and scenarios of the challenges facing the industry.

The research framework relies on System Dynamics (SD), a Systems Thinking (ST) approach whereby the problem definition is often revisited and revised as the model, or the researcher’s understanding evolves (Reynolds and Holwell, 2010; Mingers and Rosenhead, 2004). SD has been applied before to ELV contexts with varying degrees of involvement from the stakeholders (Amsterdam, 1993; Zamudio-Ramirez, 1996; Kumar and Yamaoka, 2007).

Within this framework several information gathering exercises are carried out (the relevant Research Objective is highlighted in brackets as ROx):

- A literature search on the Australian industry to source relevant statistics (RO1 and RO2).

- Semi-structured stakeholder interviews (dismantlers, auction houses, industry bodies, law enforcement) to help identify the business models, operational challenges, granular statistics, and most importantly the factors and influences in their operations (RO1 and RO2).

- Scenario Planning (SP) workshop involving the stakeholders to help identify the most critical trend and uncertainty, and then the scenarios and their effects on the industry in the following decade. The gathered information is used to update the qualitative and quantitative SD models under each scenario (RO1, RO2, RO3).

- Surveys before and following the SP workshop to validate the model focus areas and the outcome of the SP workshop (RO1, RO2, RO3).
1.6. THESIS STRUCTURE

- An aerial survey using Google Earth to determine premises growth over the previous decade for modelling purposes (RO2).

- Dismantling trials of ELVs to identify the characteristics of Australian ELVs and assess the financial and environmental impact of machine-based dismantling (RO4).

The knowledge gained from the overall approach leads to addressing the fifth research objective (RO5).

1.6 Thesis Structure

Figure 1.2 on page 6 provides a graphical overview of the thesis structure.

Chapter 2 provides a historical overview of automotive recycling and summarises the drivers and policy approaches to ELV management and issues with the implementation of these policies detracting from their intended effectiveness. The chapter also addresses the topic of this research, ELV recycling in Australia by identifying groups of stakeholders and essential flows and processes, presenting key statistics, highlighting an unsuccessful industry code of practice and the issues faced by the industry. The chapter sums several knowledge gaps that this research attempts to address.

Chapter 3 presents the adapted research methods and details the application in this research as well as some implementation issues. Also detailed are the data gathering activities for the semi-structured interviews, the scenario planning workshop (along with the attached surveys), the aerial survey, and the ELV dismantling trials.

Chapter 4, the first part of the results component, presents the findings and results from various supporting studies that were conducted to bridge information and data gaps about automotive recycling in Australia:

- insights and statistics about the industry gained from interview data with stakeholders.
- results from SP workshop surveys (before and after).
- dismantlers premises growth through an aerial survey.
- material composition and revenue potential of Australian ELVs.
- Gate-to-Gate lifecycle impact of machine-based dismantling.
CHAPTER 1. INTRODUCTION

Figure 1.2: Thesis Outline
1.6. *THESIS STRUCTURE*

Chapter 5 describes the qualitative, quantitative SD model, and the baseline simulation results.

Chapter 6 presents the SP workshop results and scenario-based SD models drawing a comparison against the baseline model.

Chapter 7 discusses the results by emphasising the need to treat the Australian automotive recycling industry as a complex system. The chapter highlights the impact of a nationally adopted and enforced operator licensing requirement on the SD model, and the effects of an elusive strategy - improving vehicle recyclability. The financial and environmental benefits of adopting machine-based dismantling as part of the core business model of ELV dismantlers is indicated depending on the location (which dictates the greenhouse gas co-efficient). Practical recommendations at the industry, business and government levels are then presented.

Chapter 8 wraps with the research limitations, key contributions and paths for further research in the field.
Chapter 2

ELV Recycling

This chapter begins with a historical narrative on ELV recycling investigating
drivers and issues from the early days of motoring. The section aims to provide
a reference point on drivers and issues in ELV recycling that perhaps persist.

Section 2.2 looks at ELV policies in several regions around the world while
summarising the major driving factors and highlighting the European and Ja-
panese approaches considered as best practice.

Next, in Section 2.3 the issues with the ELV policies are then discussed with
a particular focus on unintended consequences. The section argues, based on a
broader view that the policies may be failing at achieving the outcomes - especially
the environmental protection goals.

Section 2.4 provides an overview of the ELV situation in Australia based
on a limited body of knowledge. The stakeholders and processes are identified,
relevant ELV statistics are presented, the unsuccessful industry code of practice
and significant issues are highlighted.

Section 2.5 presents the knowledge gaps, considering the scarcity of data and
information on industry operations and the problems facing the ELV recycling
industry.

2.1 A Historical Perspective on ELVs

This section illuminates on the overlooked history of automotive recycling in order
to highlight some of the key drivers and issues that surrounded this activity from
the outset.

The dismantling of automobiles and sale of its parts is not a new trade or
practice. It can be traced back to the early 1910s (Los Angeles Sunday Times,
2.1. A HISTORICAL PERSPECTIVE ON ELVS

While a lot has changed since then in the automotive design and technologies as well as in the drivers and challenges for automotive recycling, the automotive recycling industry largely remains about the same: taking in ELVs as feedstock, removing valuable parts, and disposing of the remainder.

A rapid public uptake of the automobile resulted in a high vehicle retirement rate (Flink, 1990)—perhaps owing to poor quality manufacture. Shortly after, several issues relating to ELVs became apparent such as stolen cars rebirthed and old abandoned vehicles on the roadside. Similarly, a growing demand for parts for repairs has led to rapid growth in the automotive recycling industry or as was referred to in those days, the wreckers or junkyards.

The earliest piece of government regulation that oversees automobile wreckers may have been in Tuscon Arizona in 1918 where wreckers were required to maintain a record of and periodically report to law enforcement of the chassis and engine numbers of the cars undergoing dismantling. The policy aimed to curb down vehicle theft and rebirthing (Parker, 1918).

In early-1920s, Highland Park community designated a yard for scrapping old cars into scrap metal for profit, an approach that other municipalities across the US followed. While in New York where old abandoned cars proved a problem, a garbage scow was occasionally loaded with cars to dump into the ocean (Corey, 1928), in addition to thousands placed in the city dump each year (Corona, 1925).

In late-1920s automotive associations in divers US cities—beginning in Omaha, Cincinnati, Louisville and Minneapolis, funded the establishment of their own junking yards that proved profitable (Canberra Times, 1927). The junking process involved stripping valuable parts from old used vehicles collected by the car dealers. These parts would then be catalogued, priced and marketed through mail catalogues to dealers in other states. These cooperatives also helped the dealers ensure that the remnants of old cars are entirely scrapped, instead of circulating back and forth as trade-ins with outsider enterprises (Wetmore, 1928).

Within the same era, Henry Ford established a Junking Plant at Ford Works in River Rouge. The plant was initially geared to extracting materials from old ships for recycling (Associated Press, 1926). Shortly after, the recycling of old automobiles was integrated which by 1930 with a 400-unit daily capacity (Recorder, 1931). Recovered scrap materials were reused in the making of new parts for new cars. While all makes and models were taken, a reverse-assembly line was reserved for Ford cars (Border Watch, 1930).

Videographic evidence from the era that the disassembly processes used in the factory are close to or exceed today’s processes (Ford, 1930). Conveyors were
used to move old cars along the disassembly lines where parts were systemically removed. Engine oil was drained for recycling, headlight lenses and bulbs were collected, glass was recovered for further recycling. Even the interior fabric and leather were recovered and re-purposed. The recovered engines were dismantled for their reusable parts (Border Watch, 1930). The remaining hulks were crushed then moved into the furnace. Ford considered the plant quite successful that similar plants were planned for major cities across the US (Kokomo Tribune, 1931).

In 1930, the National Automobile Chamber of Commerce (later known as Automobile Manufacturers Association – defunct in 1999) proposed a similar approach under the Highway Safety Plan. The approach aimed to have car manufacturers collect old cars across the United States to rid the roads of old junked cars, perceived as hazards. Another driving concern was the possibility that worn mechanical parts may be unsafe if it were salvaged and resold (NCSHS, 1930).

When the United States entered World War II in 1941, auto manufacturers were ordered to cease production of cars and switch to military vehicles and weaponry manufacturing (Snyder, 2011). Ramping up production required primary materials that were in short supply, which led to the War Board instituting a scrapping plan of all old cars (Canberra Times, 1942).

The car scrapping plan was carried out between 1942 and 1945 and saw the steel in many old vehicles recycled into tanks, armour, grenades and guns, while reclaimed rubber from old tyres and floor mats ended up in new tyres for military trucks and bomber aircraft (Barringer, 1954).

During that period, and because of the rationing of the sale of new vehicles that had been stockpiled before the War Board forcing auto manufacturers to switch production, the demand for used parts to maintain America’s 30-million car fleet increased that the associated trade became attractive and lucrative (Snyder, 2011). The mean age of the fleet before the war had been under six years, while in 1946 it increased to almost nine years (Hamilton and MacAuley, 1998).

In the late 1960s, vehicle abandonment re-surgd (Rusin, 1969) as a result of two main factors: technological changes to steelmaking\textsuperscript{*} reducing the demand and the value of scrap steel, and an increase in labour costs (Field and Clark, 1991). The issue was particularly concerning to Sweden and Norway that adopted deposit-refund schemes for ELVs later in the 1970s (OECD, 1981).

\textsuperscript{*}From open hearth to basic oxygen steel manufacturing (Allen, 1994).
2.2 Drivers and Policy Approaches to ELV Policies

Moving closer to today and over the past few decades, minimising the car’s impact on the environment throughout its lifecycle has gathered much interest from policymakers and car manufacturers. A standout example is the efforts to improve the fuel economy and lower the emissions of new vehicles. Legislators hope that the growing car fleets will consume less fossil fuel - a finite and dwindling resource (Harrington, 1997).

Similarly for ELVs, primary ELV policy drivers include the decrease of ELV-generated waste - particularly the Automotive Shredder Residue (ASR), ending up in scarcer landfills, with the hazardous waste component reduced or eliminated, and improving resource recovery (Zoboli, 2000; Staudinger and Keoleian, 2001; Lundqvist, 2004; Joung et al., 2007; Niza et al., 2014). In addition to the sustainability-centric drivers for ELV policies, other drivers include:

- Security and safety: tackling vehicle abandonment (e.g. Nordic countries in the 1970s) and vehicle theft and rebirthing (e.g. the Tuscon Arizona anecdote from 1918).

- Political and legal: such as the politically-motivated response of French auto manufacturers in the 1990s to voluntary agreements in Germany (Börkey et al., 1999; Orsato et al., 2002), and the legal obligations of transposing the European Union (EU) ELV Directive into local state laws (Zoboli, 2000).

So far, the EU, the European Free Trade Association (EFTA), Japan, South Korea, China, Taiwan and Russia adopted government ELV policies. Targets for better recovery of materials and energy from ELVs and requirements for proper handling and dismantling of ELVs were set and pursued in the EU, Japan, South Korea and Taiwan (Chen, 2006; Wen et al., 2009; Chen et al., 2010; Wilson et al., 2012; Sakai et al., 2014).

These policies generally fall under either the Extended Producer Responsibility (EPR) or Product Stewardship (PS) frameworks. EPR accords the primary responsibility to the producer for the reuse, recycling or disposal of a product. PS, by contrast, introduces the concept of shared responsibility of a product throughout its use life cycle among the manufacturers, importers, governments and consumer (Waste Policy Taskforce, 2009).

It is worth pointing that in the 1990s the automotive industries in Germany, France and Spain, among others, voluntary agreements on ELVs (Bontoux et al., 1996; Zoboli, 2000), paving the way for the EU-wide policy (Börkey et al., 1999).
Taiwan enacted the “End-of-life Vehicle recycling guidelines” in 1994 to standardise the automotive recycling practice. Then in 1998, the Recycling Fund Management Board (RFMB) was established to oversee the collection of a recycling fee from automotive enterprises (manufacturers and importers) and for providing incentives and subsidies to the public and automotive recyclers for the proper disposal of ELVs. The RFMB also licenses, audits, certifies and accords performance ratings to automotive recyclers (Wen et al., 2009; Chong et al., 2009; Chen et al., 2010). The performance ratings include the output/input of dismantlers (e.g. ELVs or materials processed per worker or per energy unit (kWh), and the amount of energy used per ton of ELV). Taiwan’s approach resulted in a smaller but regulated industry that handles on average 80% of generated ELVs while achieving a 95% recovery/recycling rate on the processed ELVs (Chong et al., 2009; Wen et al., 2009).

Taiwan’s RFMB - the authority overseeing the implementation, collects a recycling fee on new vehicles sold from the vehicle manufacturers and importers. The recycling fee depends whether the car meets a green design standard or not (TW$2700 or TW$3800 per new vehicle respectively - equivalent to AU$95-122 and AU$140-170 depending on the AUD-TWD exchange rate (RBA, 2016)). The funds are then used to provide incentives to the public and subsidies to the recyclers in the hope to maximise the number of ELVs entering the system and are handled in an environmentally responsible manner (Wen et al., 2009).

Efforts to regulate automotive dismantling are underway in India (CPCB, 2015), Turkey (Cumbul Altay et al., 2011), as well as in Mexico and Vietnam (Toyota, 2014). In Canada, an Environmental Code for the industry (ARC, 2012) has been recently supplemented by provincial regulations in Ontario with other Canadian provinces to follow (OARA, 2016).

The ELV policies vary in terms of the oversight, the metrics used and the designation of the entities responsible for the financial costs of recycling despite sharing similar goals of reducing the environmental impact of ELVs as well as ELV handling requirements such as vehicle depollution and removal of hazardous parts (Sakai et al., 2014).

Numerous comparisons of ELV policies and the respective industries have been conducted, notably (Nakajima and Vanderburg, 2005; ERIA, 2009; Che et al., 2011; Harraz and Galal, 2011; Wilson et al., 2012; Azmi et al., 2013; Sakai et al., 2014). The most prominent approaches, considered best practice remain those followed in the EU and Japan (Hedayati and Subic, 2008) are summarised below. It is important to note that in Australia and since 1997 an industry code
of practice (APRAA, 1999) was pursued by an automotive industry peak body but with limited success (VACC, 2006). This code of practice is explored in detail in Section 2.4.4.

2.2.1 The European Union

The EU ELV Directive, an EPR type policy, addresses critical areas relating to automotive recycling in the vehicle life cycle from the cradle to the grave for vehicles designed for carrying less than nine passengers, and with a gross weight of 3.5t or less:

- Prevention (relative to car manufacturers and associated suppliers): dictated limiting the use of hazardous materials in car manufacturing. It also set out provisions for design, dismantling, reuse and recovery. It also encouraged an increase in the use of recycled materials. Lead, Mercury, Cadmium and Hexavalent Chromium were to be banned by January 1, 2003.

- Collection: provision of an adequate collection system which ensures that all ELV are taken up by authorised treatment facilities. It calls for a deregistration process which issues a certificate of destruction for every dropped-off ELV. The last owner of an ELV bares no cost associated with ELV treatment, except where main parts, such as engine/transmission, of the vehicle are missing.

- Treatment: the ELV storage and treatment must be environmentally sound which implies regulating the treatment process. The adoption of certified environmental management systems was encouraged.

- Reuse and Recovery: through reuse, recovery and recycling of car parts. The general targets for reuse/recovery were set at 85% by 2006 and 95% by 2015.

- Coding standards and dismantling information: car manufacturers and part-makers must use component and material coding standards to help identify parts that are suitable for reuse and recovery when dismantling the vehicle. Car manufacturers must also provide dismantling information on new models and the location of hazardous materials and make the information available to authorised dismantling businesses.
Most member nations of the European Union transposed the directive into local laws with slight variations to recycling goals and zero liability to the consumer condition and reporting frameworks (Fergusson, 2006). However, the policy adoption and enactment process was slow despite that some countries already had laws or voluntary industrial agreements that dealt with the ELV predicament (Zoboli, 2000); furthermore, the implementation proved problematic in regards to measurement of recycling and recovery rates as well as on collection of associated statistics throughout the reverse supply chain (Lucas, 2001).

2.2.2 Japan

The Japanese Automobile Recycling Law in 2002 came in effect in January 2005. The law, which is a PS policy, covers all forms of four-wheeled vehicles irrespective of size or weight. Under the law, car manufacturers are responsible for handling the ASR, fluorocarbons, and airbags generated from ELV dismantling and shredding. Vehicle owners bear the cost of ELV treatment via a fee collected at the time of new car purchase or at the time of vehicle inspection for older vehicles.

The Japanese law places heavy emphasis on the information management required for funding and reporting purposes. The law also set the ASR recycling targets to 30%, 50%, and 70% to be reached by 2005, 2010, and 2015 respectively. Also, 85% of airbags need to be recovered from the total number of ELV treated. It is worthwhile mentioning that several Japanese car manufacturers had by 2009 met or exceeded the 2015 recycling targets (Sakai et al., 2014).

2.3 Issues with ELV Policies

Observing the common issues of ELV policies from a theoretical and practical standpoint, two major groups of issues emerge:

1. The first cluster revolves around the theoretical foundation of these policies failing to:
   
   (a) Address the fundamental problem, that vehicles are not designed for recycling from the grounds up (Lashlem et al., 2013; Rahimifard et al., 2009). Despite the design for (recycling, re-use, remanufacturing, disassembly) approaches that some policies promote, notably the EU Directive, their impact remains limited which detract from reaching a more sustainable vehicle production (Gerrard and Kandlikar, 2007).
2.3. **ISSUES WITH ELV POLICIES**

These approaches are perceived as mere add-ons to the automobile design process, not a complete re-imagining of the vehicle, only resulting in short-term technological improvements (Smith and Crotty, 2006).

(b) Fully appreciate the complexity of ELV recycling because among many factors the activity involves a multitude of stakeholders, differing drivers for recycling by country and even state, and continually changing challenges -such as arising environmental and societal issues (Dobers and Wolff, 1999).

2. The second cluster of issues relates to unintended consequences, explicitly shifting the ELV problem outside the proper treatment channels, discussed in (Appendix A) and highlighted by (Sawyer-Beaulieu and Tam, 2006; Kumar and Yamaoka, 2007; Letsrecycle.com, 2007; Ogushi and Kandlikar, 2007; BMU, 2009; Che et al., 2011; Wilts and Bleischwitz, 2012; Zorpas and Inglezakis, 2012), manifested through:

(a) The used car export issue: whereby an increase in the exports of used cars is observed post-ELV-policy adoption in the Netherlands, Japan, UK and Germany. An unintended consequence is encouraging the export of ELVs across the borders through regulation loopholes acting as hidden incentives, often to countries that lack the resources and legislation for environmentally safe end-of-life treatment. The export statistics from the countries highlighted in suggest that the bulk of used-car exports were heading to Africa (e.g. Algiers, Nigeria), and the eastern states of Europe.

(b) The inadequate information management and reporting infrastructure: where loopholes in the deregistration process (such as in the UK), and inadequate reporting requirements (e.g. Germany) leaves the fate of a significant number of ELVs to the unknown.

Based on the forwarded view and given the lack of coordination or standardisation among the ELV policies, the effectiveness of the policies in improving the environmental outcome of ELV recycling at an absolute or macro scale becomes highly questionable. The policies may only be improving the outcomes at the micro levels of the process: such as at the level of dismantling rendering it more environmentally-responsible (Wilson *et al.*, 2012; Zorpas and Inglezakis, 2012), at
the level of material recovery and recycling - recouping and recycling more (Fonseca et al., 2013; Niza et al., 2014), and the containment of hazardous materials (Sakai et al., 2014).

2.4 ELV Management in Australia

This section describes the current ELV situation in Australia, by presenting the groups of stakeholders, highlighting important statistics on ELVs, presenting the voluntary industry code of practice, and highlighting some of the pressing issues. Through this overview of ELV recycling in Australia, a lack of information in several areas can be seen. These gaps represent barriers to a thorough assessment of the Australian situation and to proposing informed policy and strategy options.

2.4.1 Stakeholders in ELV Recycling in Australia

There are interacting groups of stakeholders in the automotive recycling as various factors (economic, social, environmental, policy) influence the flows of ELVs and its parts. Each group pursues their own goals and interests, which in the case of dismantlers is profit (Allan, 2007). Adapting an automotive value chain perspective (Coates, 2007), the stakeholders within and around the Australian system of automotive recycling could fall into two main categories. The shortlist below serves to indicate the complexity of automobile recycling as it involves a myriad of stakeholders whose individual interests may not align and whose influence in effecting policy change varies (Gilmour, 2006):

- Upstream, those on the supply side of new vehicles and replacement parts:
  - car manufacturers and importers: play a significant role, although understated and delayed, because their design and materials choice (and choice of models to bring into the market for importers) influence the recyclability and economics of ELVs.
  - replacement parts manufacturers and suppliers: the design and materials choice of parts, as well as parts availability and pricing of parts, potentially influence the value of used parts extracted from ELVs.

- Downstream, those on the treatment side of ELVs:
  - secondhand car dealers and the car auction houses: handling used and damaged vehicles.
2.4. ELV MANAGEMENT IN AUSTRALIA

– logistics operators such as towing services: engage primarily in the transport of damaged vehicles and ELVs among other stakeholders.

– car insurance industry: providing insurance services for motorists. It also plays a crucial role in determining whether a damaged vehicle is sent for repair or sold for salvage.

– automotive repairs industry: a significant demand stream for parts. The repairers also play a role in the assessment of a damaged vehicle for repair.

– scrap metal recycling industry: purchasing and recycling scrap metal and ELV hulks from automotive recyclers.

– tyre recycling and fluids recycling industries: providing (at a cost) waste collection/recycling services to the automotive recyclers and repairers.

– automotive dismantlers and used parts dealers (the focus of much of this work): dealing mostly with the purchase of ELVs,

– consumers (including mechanical repair businesses): influence the rate of disposal of vehicles by deciding whether to replace or repair, an old or damaged vehicle —Also, Do-It-Yourself (DIY) consumers seeking used parts to repair their vehicles. In addition, the consumers’ attitude towards accepting a used or remanufactured part versus a new one plays a role in the demand for recovered parts from ELVs.

Furthermore, and tangent to these two categories are the:

• governments (federal, state, local) and law enforcement agencies: setting, administering and enforcing laws that influence the behaviour of all the stakeholders,

• research organisations: such as universities and cooperative research centres with research on automotive recycling, and lastly the

• industry and consumer associations and peak bodies: representing the various industry and consumer sectors, advocating and bringing forward the concerns of their members and industries to the government, and providing support to their members such as:
Federal Chamber of Automotive Industries (FCAI): the peak industry organisation representing the manufacturers and importers of vehicles in Australia (FCAI, 2016).

Australian Imported Motor Vehicle Industry Association (AIMVIA): an organisation representing “businesses associated with the importation, preparation, and sale of used vehicles” (AIMVIA, 2016).

Motor Trades Association of Australia (MTAA): the peak body for state and territory motor trade associations and automobile chambers of commerce (e.g. Motor Trades Association of ACT (MTAACT), Victorian Automobile Chamber of Commerce (VACC)). The state or territory bodies span multiple stakeholder groups in the automotive industry (MTAA, 2015).

Auto Parts Recyclers Association of Australia (APRAA): an affiliated trade association of MTAA. APRAA represents, through a federation model, the auto parts recyclers that are members of the state or territory motor trade association/chamber of commerce (APRAA, 2004). APRAA claimed to represent 30-40% of the 800-900 legitimate operators in the Australian industry (Australia, 2002).

Auto Recyclers Association of Australia (ARAA): an independent association pursuing the interests of auto parts recyclers (including operators who dismantle as a secondary business activity, and affiliated operators) through a direct and free membership rather than the federation model of APRAA (ARAA, 2014).

Australian Automobile Association (AAA): the peak organisation for motoring clubs in Australia, such as National Roads and Motorists’ Association (NRMA) and Royal Automobile Club of Victoria (RACV), AAA (2016).

2.4.2 Flows and Processes in ELV Recycling

The ELVs flows and processes of dismantling in Australia have been extensively covered, although not statistically, through video-graphic reports (Moore, 1991, 1994, 1999, 2000; TAR, 2007) as well as in published reports (Australia, 2002; VACC, 2006; TAR, 2007; Allan, 2007; McNamara, 2009; Brodribb and McCann, 2015). At the most basic level, three key steps are identified:
• Sourcing of ELVs: purchase and transport of ELVs from the last owner, an auction house, a car dealer, towing service companies dealing with ELVs, or even from overseas.

• Processing of ELVs:
  – ELV depollution (not mandatory): removal of hazardous parts (e.g. battery, airbags), fluids and gases (e.g. engine oil, coolant or antifreeze, hydraulic fluids, fuel, refrigerant gas, Liquid Petroleum or Natural Gas for vehicles on gas).
  – Storage: in an open-air yard or closed hangar.
  – Dismantling and removal of parts: either systemically (by hand and using machines), on-demand, or by the consumer (mostly for Pull-It-Yourself type recyclers).

• Disposal of ELV hulks, remnant parts, and fluids/gases to into respective recycling industries (e.g. metals, tyres, batteries, oils) where further processing is carried out (e.g. shredding of compacted hulks for metal recovery).

No data could be sourced on the prevalence of ELV depollution in the industry, nor about the length of period ELVs are kept on premises among many unreported factors.

2.4.3 Key Statistics

When discussing the current ELV situation in Australia, it is essential to highlight relevant statistics to illustrate the volume of ELVs handled, the characteristics of the Australian ELV, and most importantly the industry of automotive recyclers. Estimates are presented where possible as most of the data on the ELVs and the industry is scarce or non-existent.

2.4.3.1 Automotive Fleet and ELVs

The ELVs in Australia are dismantled and shredded by a network of profit-driven recyclers throughout the country. No data is currently collected by the road traffic authorities or any official body on the fate of unregistered vehicles (Allan, 2007). However, an estimate of attritioned vehicles is published annually (ABS, 2013).
In 2001 the operators handled estimated 500,000 ELVs (Australia, 2002). The figure for 2010 estimated put at 750,000 ELVs based on the growth rate of vehicle ownership between 1991 and 2001. Considering that the actual fleet growth between 2001 and 2009 came to be around 24% (ABS, 2013) (Figure 2.1 on page 25). Using the original 500k estimate and the actual fleet growth rate, the number of ELVs handled in 2010 can be first assumed around 625,000 units.

Given that this figure includes exported ELVs the actual number of ELVs handled by the industry (including scrap steel recyclers and non-legitimate operators) is likely to be less.

During the late 1990s, the export of used vehicles was negligible. Between 1998 and 2008 the activity grew by a significant 145-fold (Figure 2.2 on page 25). Assuming that the number of exported actual ELVs is an insignificant portion (less than 20% of exported used cars -the volume of exported used vehicles represents 12.29% of vehicles attritioned at its reported peak in 2008 (DFAT, 2012; ABS, 2013)), the number of ELVs that can be removed from the estimated 625,000 units can therefore be around 15,000 units. The resulting figure of about 610,000 ELVs handled in Australia in 2010 could be used as a base estimate†.

It is worthwhile comparing the number of ELVs metric along with other indicators with other countries. The ELV severity metric suggested and calculated in Table 2.1 on page 24 serves to indicate the gravity of ELVs in various countries concerning the population and land area size. In this comparison, the ELV severity metric in Australia is significantly lower than all countries, and particularly those with ELV policies.

2.4.3.2 ELV Characteristics

No data is collected on the average age of the Australian ELV nor about its weight and material composition. There are, however, estimates around these figures as discussed below.

**ELV Age** Not to be confused with the average age of the Australian automotive fleet (excluding HCVs) - estimated at 10.27 years (ABS, 2013), the average age of ELVs in Australia is following a decreasing trend (AAI, 2009). This trend is due to a growing number of new vehicles expected to enter the fleet, perhaps as a result of rising vehicle affordability among other factors (Bracks, 2008).

†No relevant data could be obtained for the number of ELVs handled directly by the scrap metal industry and non-legitimate operators. A conservative estimate could be about 20% of the overall figure.
2.4. ELV MANAGEMENT IN AUSTRALIA

By contrast, the average age of PMVs and LCVs in the EU is 7.56 and 8.05 years respectively (EEA, 2015), while the average age of the ELVs in the EU is estimated between 12.1 and 15.3 years (GHK and BIOIS, 2006). Therefore, the average age of the Australian ELV may fall between 15.5 and 20.2 years.

**ELV Weight** Two sources estimate the weight of the Australian ELV at 1300kg and 1500kg respectively (Australia, 2002; Allan, 2007) reasoning that older vehicles weigh on average more than newer ones. The latter source attributes their estimate to the higher metal content of older ELVs but seems not to distinguish the metal content with the increasing overall vehicle weight of newer models (Cuenot, 2009) and the effective decrease of overall material recyclability (Van Schaik et al., 2001). As a result, the 1500kg could be treated as an overestimate.

Further supporting the 1300kg figure is an analysis of the new PMV and LCV sales data between 1991 and 2000 (AAI, 2009) (Appendix B). It is worth noting that the same analytical approach applied to the Dutch fleet data yields 1100kg (CBS, 2010). The discrepancy between the between Australia and the Netherlands’s fleets weight may be attributed to the prominence of larger PMVs and SUVs in Australia (AAI, 2009).

In the EU the average ELV weighs 930kg, while in the Netherlands 944kg (Eurostat, 2013). This discrepancy between the average vehicle weight (deduced from automotive segments or sales) and reported ELV weight, suggests that the 1300kg figure for the Australian ELV could be an overestimate.

**ELV Material Composition** The material composition of ELVs plays a significant economic role at the recycling stage as it determines the recoverable and saleable materials generating revenue (e.g. scrap steel, precious metals, batteries) and those that ensue liability for disposal costs (such as tyres).

No relevant data is available on the composition of the Australian ELVs. Rough estimates are around 70% for steel and ferrous metals and about 9% for plastics (Australia, 2002; Allan, 2007).

Similarly, no trials have been conducted to evaluate the proportion of hazardous materials (such as Lead, Mercury, Chromium) and fluids (e.g. coolant, brake and hydraulic fluid, engine oil) in the Australian ELVs. Normalising the data from a US example (Staudinger and Keoleian, 2001)to the 1300kg Australian ELV, it is estimated that the ELV contains 29.9kg of hazardous materials and 23.1kg of fluids (figures obtained from BMW in 2009 during a site visit to their Recycling & Dismantling Center in Unterschleißheim, Germany.).
2.4.3.3 ELV Recycling Industry Statistics

It is worth pointing out that the classification of the downstream group of stakeholders in Section 2.5.1 is far from definite. Many operators belong to more than a single category: most of the automotive recyclers engage in one or more additional business activity such as used car dealing or mechanical repairs (VACC, 2006; IBISWorld, 2011). Similarly, some mechanical repairers carry out automotive dismantling occasionally. No data could be found about this diversity in the business models.

As a result, the reported industry statistics below should be treated as a rough estimate for the operators whose primary modus operandi is automotive recycling (e.g. 60% of income is from dismantling of ELVs and sale of parts or scrap materials). ARAA estimates that the number of operators in Australia with links to automotive recycling exceeds 1500 (ARAA, 2015). The majority of operators are located in major industrial zones throughout metropolitan areas in Australia with few in remote regions (Figure 2.3 on page 26), permitting easy access to other industries supplying ELVs, and client industries (VACC, 2006).

Following years of steady growth (13% in revenue and 7% profit) between 1999 and 2004 and estimated 1000 operators in 2004 (VACC, 2006), the automotive recycling in Australia is seen as a declining industry -experiencing a decline in demand for its products/services for an extended period (Jan, 1995), with reference to the shrinking number of operators (Figure 2.4 on page 27), together with a decline in employment (Figure 2.6 on page 28) and a stagnation in revenue growth between 2007 and 2011 (Figure 2.5 on page 27) (IBISWorld, 2011).

Before this period, the Australian automotive recycling industry may have enjoyed even more extended periods of growth over several decades, perhaps as a result of Government policies adopted since the 1960s to protect and encourage local automotive manufacturing (Conlon and Perkins, 2001). These protectionist mechanisms have inadvertently contributed to keeping more old cars on the road than in other countries (evidenced in the Australian ELV age being significantly higher than in the EU), encouraging a repair-and-maintain attitude and fuelling the automotive dismantling trade (IBISWorld, 2005). This perspective is summarised in Table 2.2 on page 28.

Main cost factors for operators are ELV purchases, wages, and rent representing 61.3%, 13.4% and 5.9% of operational costs respectively (VACC, 2006; IBISWorld, 2011).
2.4. ELV MANAGEMENT IN AUSTRALIA

2.4.3.4 Notes on the Used Parts and Scrap Metals Recycling Markets

Despite the implied importance of dismantling in the recovery of quality re-usable parts, the used parts market is estimated at just under 3% of the overall parts market (e.g. new and OEM) in Victoria (TAR, 2008). By comparison, the figures in Japan and the US are 4.7% and 2.5% respectively (METI, 2007; IBISWorld, 2009).

There is no official data on ELV shredding and materials extraction in Australia. The metal recovery rate from shredder flock is estimated at least 98%. The estimated recovery rate (by weight) of steel from a shredded ELV is around 70% with the remainder going to landfill. Post shredder non-metal processing is non-existent (Australia, 2002). Ferrous metals reclamation from shredders output is a standard profitable practice with under ten enterprises handling well over 80% of all metal recycling in Australia (ACOR, 2009).

Although the LPG powered vehicles making up 2.86% of PMVs and LCVs some metal recyclers in Australia do not accept ELVs containing LPG gas tanks due to safety concerns (Norstar, 2010). The fate of LPG tanks is unclear.

As for the hybrid vehicles, Toyota Australia has a take-back process for handling Nickel-Metal Hydride batteries from their hybrid ELVs (Toyota and Lexus) which involves the collection and processing at no cost to the consumer (TMCAL, 2008).

2.4.4 ELV Recycling Industry Code of Practice

Despite comprehensive business and industry-oriented licensing requirements in Australia, none exist for dismantlers intending to deal specifically with ELVs (Victoria Police, 2014). Industrial waste guidelines set by the state or local council provide broad approaches but vary between jurisdictions.

There are also gaps in current regulations and inconsistencies among states regulations that govern the operators licensing and vehicles registration (Allan, 2007; AMIF, 2014). Table 2.3 on page 31 highlights some of the laws, directly and indirectly, influencing the automotive recycling sector in Australia.

Furthermore, there are no incentive or requirements for the last owner of a vehicle to deregister it and to ensure that the ELV gets processed in an environmentally friendly manner (Allan, 2007).

As mentioned earlier, a voluntary code of practice for the automotive recyclers in Australia (APRAA, 1999) was prepared and promoted by APRAA with limited success - only small number of recyclers (71 out of an estimated 800) adopted
### Table 2.1: A Comparison of Country Indicators

<table>
<thead>
<tr>
<th>Country</th>
<th>ELV Policy</th>
<th>Population (M)</th>
<th>Area ('000 sq km)</th>
<th>Population Density (ca/sq km)</th>
<th>Cars in Use (M)</th>
<th>Capita per Vehicle</th>
<th>Car Production (&quot;000)</th>
<th>New Car Sales (&quot;000)</th>
<th>Net Cars Importer or Exporter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>USA</td>
<td>24</td>
<td>7750</td>
<td>3.09</td>
<td>11.8</td>
<td>2.03</td>
<td>160</td>
<td>924</td>
<td>I</td>
</tr>
<tr>
<td>Germany</td>
<td>USA</td>
<td>82</td>
<td>9857</td>
<td>31.35</td>
<td>136</td>
<td>2.27</td>
<td>4163</td>
<td>7517</td>
<td>E</td>
</tr>
<tr>
<td>Japan</td>
<td>USA</td>
<td>61</td>
<td>357</td>
<td>229.69</td>
<td>41</td>
<td>2.00</td>
<td>5708</td>
<td>3026</td>
<td>I</td>
</tr>
<tr>
<td>South Korea</td>
<td>USA</td>
<td>127.5</td>
<td>244</td>
<td>250</td>
<td>27</td>
<td>2.26</td>
<td>1588</td>
<td>2634</td>
<td>E</td>
</tr>
<tr>
<td>Canada</td>
<td>USA</td>
<td>49</td>
<td>9985</td>
<td>337.30</td>
<td>15</td>
<td>3.27</td>
<td>7831</td>
<td>4126</td>
<td>I</td>
</tr>
<tr>
<td>Taiwan</td>
<td>USA</td>
<td>23.5</td>
<td>9985</td>
<td>652.77</td>
<td>6.6</td>
<td>1.73</td>
<td>4315</td>
<td>1534</td>
<td>I</td>
</tr>
<tr>
<td>New Zealand</td>
<td>USA</td>
<td>61</td>
<td>268</td>
<td>16.42</td>
<td>2.7</td>
<td>1.63</td>
<td>0</td>
<td>100</td>
<td>E</td>
</tr>
<tr>
<td>USA</td>
<td>USA</td>
<td>304</td>
<td>357</td>
<td>229.69</td>
<td>41</td>
<td>2.00</td>
<td>5708</td>
<td>3026</td>
<td>I</td>
</tr>
</tbody>
</table>

**Notes:**
- °: CIA, 2016
- ‡: OICA, 2016 (Worldometers.info, 2016)
- §: OICA, 2016
- †: OICA, 2016
- **: Canada exports most locally produced cars to neighbouring USA (Van Biesebroeck et al., 2012)
- "": The references for the ELV figures: Australia (as per the estimate presented in Section 2.4.3), for New Zealand (Cassells et al., 2005), for USA, Germany, Japan, South Korea and Canada (Sakai et al., 2014), and for Taiwan (Cheng et al., 2012).

Canada exports most locally produced cars to neighbouring USA (Van Biesebroeck et al., 2012).
2.4. ELV MANAGEMENT IN AUSTRALIA

Figure 2.1: Australian Automotive Fleet and Attritioned Vehicles
(Data Source: ABS, 2013)

Figure 2.2: Exported Used Vehicles
(Data Source: DFAT, 2012)
Figure 2.3: Locations of Australian Automotive Recyclers
(Data Source: ARAA, 2015)
2.4. ELV MANAGEMENT IN AUSTRALIA

Figure 2.4: Automotive Recyclers
(Data Source: IBISWorld, 2011)

Figure 2.5: Automotive Recyclers Revenue and Profit
(Data Source: IBISWorld, 2011)
CHAPTER 2. ELV RECYCLING

Figure 2.6: Workforce Size
(Data Source: IBISWorld, 2011)

<table>
<thead>
<tr>
<th>Policy</th>
<th>Possible effects on the automotive recycling industry in Australia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protectionist government policies during the 60s (tariffs and quotas on imported vehicles) (Conlon and Perkins, 2001)</td>
<td>Industry experiencing growth in the 1970s through to the early 2000s as local market is constrained to locally produced cars and components.</td>
</tr>
<tr>
<td>Button Plan 1984 - 1992 (Owens, 1995; Conlon and Perkins, 2001; AAI, 2009)</td>
<td>Growth plateau and some operators forced out of business as there is a shift from the previous practice (service and maintain old vehicles) to a disposal practice with more affordable vehicles.</td>
</tr>
<tr>
<td>Gradual reduction of import tariffs on imported vehicles from the early 2000s (AAI, 2009)</td>
<td>More pressure on the industry to remain in operation (with improving new car affordability, further accelerates the attrition rate of cars and demand for used parts).</td>
</tr>
</tbody>
</table>

Table 2.2: Possible Automotive Policy Effects on the State of Automotive Recycling in Australia
2.4. ELV MANAGEMENT IN AUSTRALIA

the code (APRAA, 2007) with no new members accredited since\textsuperscript{\ddagger}. The voluntary code addresses the following principal areas of operations for dismantlers as summarised below:

- **Occupational health, safety and environment (OHSE):** covers stormwater management, hazardous waste management, fluororubber adhesives, refrigerant gases, batteries, airbags, state and local OHSE requirements, and the identification of emergency contacts.

- **Basic requirements and equipment:** covers the storage of hazardous materials in secure containers, carrying out the dismantling indoors on a sealed surface, the storage of parts in a manner to prevent residues from reaching the stormwater drains, establishes a code of conduct relating to stormwater management, trade wastewater permits as per state or local laws, air quality management (containment of gases, fumes, dust to avoid contact with lungs, skin and the environment), waste management (minimisation of waste going to landfill, workplace practice around waste), and noise management (limiting the use of noisy equipment to business hours, adopting noise abatement methods, and providing hearing protection).

- **General procedures and guidelines:** establishes procedures for disassembly (removal of the battery, drainage of fluids and gases, and the removal of airbags), containing spills and cleaning, storage of hazardous materials, engaging with approved professional contractors for disposal.

- **Auto parts recycling guide code:** the code is used in the guide to help recyclers identify and distinguish between hazardous materials (red), reusable materials (blue), recyclable or can be remanufactured (green), designated materials for collection by an authorised contractor (yellow), and disposable waste (black).

- **Recycling auto parts:** sets out a detailed reference manual for operations covering the initial procedure, the handling of plastics, metals, liquids, tyres, hazardous materials, and other waste. The tabulated manual categorises components providing a clear breakup of materials, a recommended dismantling process, storage, disposal and safety precautions.

\textsuperscript{\ddagger}Stakeholders in the industry have attributed the failure to promote the code to political issues in the peak bodies, organisational changes in the industry peak bodies, and the prioritisation of other matters over automotive recycling which is seen as a small subset of after-market operators (Source: contacts in the industry wishing to remain anonymous).
This code of practice remains as the most comprehensive effort to standardise parts dismantling and material recycling in Australia (APRAA, 2010).

### 2.4.5 ELV Recycling Industry Issues

There is limited information on the challenges that the industry faces. Among the prominent reported, are issues with competition from unregulated operators, lack of government regulations on ELV recycling, and the affordability of imported parts as well as new cars:

- Australian legitimate operators face competition from unregulated (or backyards) operators as a result of few barriers and licensing requirements for establishing operations (VACC, 2006). Being mindful about leaks into the environment are perhaps secondary to business goals to most operators. For the backyards, these environmental considerations may not even exist and therefore may be considered as a grave concern.

- Lack of government support (through policy or incentives) on vehicle de-pollution and insufficient enforcement for the correct and safe disposal of vehicles (Australia, 2002; VACC, 2006) which further reinforces the environmental concerns as well as concerns about the backyards flourishing. Also relating to this dimension, the unknown fate of almost 90% of refrigerant gases in ELVs (Brodribb and McCann, 2015), and almost 30% of old batteries.

- Low tariffs on imported parts and rising new vehicle affordability encouraging the public to opt for new instead of used (VACC, 2006; AAI, 2009; IBISWorld, 2011) which poses as a fundamental problem for the business case of automotive recycling, perhaps causing some operators to fold or switch operations to other business models.

### 2.5 Literature Gaps

Looking back at the history of ELVs, the current ELV policy landscape, issues with the policies, and taking into account the uniqueness of the Australian situation and the relative scarcity of data and information about the Australian industry and ELVs, the following literature gaps were identified:
## 2.5. LITERATURE GAPS

<table>
<thead>
<tr>
<th>Federal</th>
<th>State / Territory</th>
<th>Local / Municipality</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Hazardous Waste (Regulation of Exports and Imports) Act 1989</td>
<td>• QLD: Motor Vehicles and Boats Securities Act 1986</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• SA: Motor Vehicles Act 1959</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• TAS: Motor Vehicles Securities Act 1984</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• ACT: Road Transport (Vehicle Registration) Act 1999 and Regulations 2000.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• NT: Motor Vehicles Act.</td>
<td></td>
</tr>
</tbody>
</table>

Table 2.3: Some of the Laws Potentially Influencing ELV Recycling in Australia
1. Limited information about the operations of Australian ELV recyclers, such as the sources of ELVs, processing, disposal, and revenue streams or markets and the influencing factors for these operations.

2. Limited information about the Australian ELV recyclers businesses (workforce and premises area size).

3. The impending operational issues and challenges facing the Australian ELV recycling industry.

4. The type of ELV policy that may be effective at addressing the issues without causing significant unintended consequences.

5. The financial and environmental impact of using a multi-dismantling machine for further in-house material segregation of ELVs.

Conclusions

This chapter presented a literature review of ELV recycling, providing a historical and global perspective. It tackled the policy approaches and issues with these policies. It also highlighted the Australian situation drawing attention to the scarcity of information and data that this research intends to address. The following chapter details the methodology followed.
Chapter 3

Research Methodology

This chapter begins by explaining the methodological framework including SD stages, its applicability to complex systems, how it fits in the overall learning context and how it was adapted to this research.

Sections 3.2 and 3.3 present the methods for two main data gathering activities, stakeholder interviews and scenario planning workshop respectively. Section 3.4 covers the methods for the supporting studies: the aerial survey using Google Earth, the ELV dismantling trial, and Gate-to-Gate Lifecycle Inventory of using a multi dismantling machine for ELV recycling. Figure 3.1 on page 34 provides an overview of these sections.

Lastly, section 3.5 highlights the ethical considerations for this research.

3.1 Research Framework

This section covers some of the basics of SD used as a Systems Thinking (ST) approach -along with background information on ST, and a problem structuring method into the Australian ELV recycling industry. This section also looks at the stages of the SD approach while emphasising its iterative character.

ST could perhaps be best described as a

\[ \text{\ldots set of synergistic analytic skills used to improve the capability of} \]
\[ \text{identifying and understanding systems, predicting their behaviours,} \]
\[ \text{and devising modifications to them in order to produce desired effects.} \]
\[ \text{These skills work together as a system. (Arnold and Wade, 2015)} \]

Under the umbrella of ST, there are several well-developed problem structuring methods next to SD such as the Soft Systems Methodology (SSM), Viable
Figure 3.1: An Overview of the Methodology Chapter
3.1. RESEARCH FRAMEWORK

System Model (VSM) and Strategic Options Development and Analysis (SODA) (Mingers and Rosenhead, 2004). Depending on the complexity of the problem or “mess” being tackled, the stakeholders’ relationships among each other and the ultimate aim of the intervention, some methods may be better suited than others (Flood and Jackson, 1991), although mixing and matching has become acceptable (Mingers and Rosenhead, 2004). To better illustrate, the following account provides a snippet on the evolution of ST methods based on the views of Midgley (2000).

The various problem structuring methods exist in an evolving ST domain, which is in its third generation or wave. The first ST wave (between the 1950s and 1960s) characterised methods that attempt to model or represent reality without proper involvement of the stakeholders (often carried out by an outsider or expert), objectify humans by focusing on quantitative modelling and assume the overall goal of the system being analysed is given or above debate. The first wave of ST includes SD in its early forms and VSM (Midgley, 2000).

The second ST wave of methods (from the late 1960s to early 1980s), carrying greater social focus and qualitative modelling, attempted to address the shortcomings of the first wave by according significance to the qualitative aspects of modelling and thus rely on significant stakeholder involvement. However, these methods were perceived as lacking in terms of conflict management (i.e. among viewpoints of participants). SSM and Interactive Planning (IP) are examples of the second wave of ST methods (Midgley, 2000).

The third wave of ST (from the early 1980s) brought about an awareness and acceptance of mixing multiple methods from the first two waves. Moreover, both quantitative and qualitative modelling are viewed as complementing each other, not opposing (Jackson and Keys, 1984). Further to this view, Midgley acknowledges that the methods themselves have been evolving and adapted to suit applications (Midgley, 2000), also supported by Mingers and Rosenhead (2004).

Of particular interest is SD, a computer-aided modelling method to aid policy analysis and design which can be applied to dynamic problems found in systems that exhibit interdependence, mutual interaction, information feedback, and circular causality (Richardson, 2013). This definition helps illustrate a polyvalent and evolving character of SD which has been applied since its inception by Jay Wright Forrester in 1959 to a wide range of problems and problem contexts (Sterman, 2000; Coyle, 2000).

SD, in its initial form, came about during the first wave of the ST method where analysts or experts scoped and modelled a system with little to no input
from the stakeholders (e.g. Meadows et al., 1974; Coyle, 1977; Bossel, 1994). But SD evolved (and continues to do so) and was used extensively in participatory contexts as a policy discussion tool from the mid-1980s (Morecroft and Sterman, 1994). SD has also been adapted to solely focus on qualitative modelling (Forrest, 2009).

In applying SD to the ELV recycling system in Australia, Sterman’s version of SD, the reiterative Modeling Process (Sterman, 2000), is used as an overall research framework. There are three main reasons for this methodological choice:

Firstly, SD was proven in a similar context: to study the effects of automotive design policies of vehicle manufacturers on the used parts trade in the US (Zamudio-Ramirez, 1996). Albeit in that application of SD which included participation of the stakeholders during model conception, the extent of stakeholder input and the specific type of information gathered was unclear. This research shall attempt to be transparent about the participation of the stakeholders, their role and input. By contrast, there are no published applications of VSM or SSM at automotive recycling with a policy assessment aim.

Secondly, SD permits to combine and place equal emphasis on quantitative modelling and stakeholder participation (Midgley, 2000). This criterion not only sets SD apart from all second wave methods, particularly SSM (Checkland and Poulter, 2006) and the evolved VSM (Espejo and Harnden, 1989) for lacking quantitative elements, but it also allows the model to quantify the effect of policies that need to be tested.

Thirdly, SD presents as the most practical and feasible choice for researching a complex system with a multitude of stakeholders and stakeholder groups whereby financial, logistical and organisational limitations would hinder or render mute any effort from applying SSM which necessitates a coalition of stakeholders reaching a consensus (Flood and Jackson, 1991) - a condition which cannot be met in automotive recycling as it involves various groups of stakeholders with competing operation and revenue goals.

### 3.1.1 SD Stages

The reiterative Modeling Process involves five stages that cover qualitative and quantitative aspects of the modelling (Sterman, 2000):

1. Problem identification: regarded as the most crucial step, whereby the underlying issue - not merely the symptoms, needs to be identified which in turn helps establish the model purpose. A clearly defined model purpose
3.1. RESEARCH FRAMEWORK

provides a higher perspective on the value and usefulness of modelling to the involved stakeholders. It also guides the modelling effort by helping find the relevant variables and historical data, known as Behaviour Over Time (BOT), that explain the problem.

2. Dynamic hypothesis: once the problem or issue is identified, the next step is to form a theory or hypothesis about the causes of the problem. The factors and influences giving rise to the problem are often presented through Influence Diagrams (ID) or Causal Loop Diagrams (CLD). These qualitative models help develop the conceptual simulation models, known as Stock and Flow Diagrams (SFD) using an SD dedicated software. The model boundary is also identified as the variables are either included (part of the problem and may be modified), assumed external (cannot be changed but has influence in the model), or excluded (assumed irrelevant or beyond the scope of the problem).

3. Model formulation: once the essential SFDs around the problem are laid out, the mathematical equations of the variables representing relationships are devised along with the initial values of variables or stocks. Simulation parameters (e.g. modelling horizon - months or years, simulation step granularity) are also set based on the purpose of the model and the availability of data for reference data.

4. Model testing: this stage involves testing the simulation results by comparing with reference or baseline data and observing the model behaviour by experimenting with extreme values for the variables. This stage aims to build confidence in the model, assumptions and variable relationships.

5. Scenarios and policy: the SD model is revised or updated with the perceived effects of the policy or scenarios that need to be tested to fulfil the model purpose. Such updates include updates to the IDs/CLDs, changes to the SFDs, variable reformulation/value changing.

It is important to note that neither the problem definition, the model purpose, nor the dynamic hypothesis is final as they are often revised or even completely changed, as modelling progresses.
3.1.2 SD and Complexity

Several SD modelling heuristics have been adapted and applied to different problem situations, such as the System Dynamics Modelling Procedure (Saeed, 1994), System Enquiry (Wolstenholme, 1990) and the Modeling Process (Sterman, 2000). While the emphasis of these frameworks has been on the approach to modelling as a whole, the SD methodology is still expanding. Some of the debate centres on determining consistent methods for tackling systems, whether as simple systems exhibiting dynamically complex behaviour (e.g. factory assembly line, predator/prey, hot shower - (O’Callaghan, 1986)) or as complex structures with messy or ill-defined problems (Lane, 2010).

In the case of simple systems exhibiting dynamically complex behaviour, the problem is often defined and treated as an optimisation exercise under specific constraints (Sterman, 2000; Maani and Cavana, 2007).

For the structurally complex systems, Flood and Jackson (1991) argue that other ST tools such as the Soft Systems Methodology (SSM) (Checkland and Scholes, 1990) or the Viable System Methodology (VSM) (Beer, 1981) are most suitable. However, there is an abundance of examples of SD application to structurally complex systems that generate valuable insights despite the high degree of difficulty in model conceptualisation and in obtaining data for mathematical modelling (Sterman, 2000).

In recognising that SD modelling is challenging in complex systems or messy
problems and that the usefulness of the complex quantitative models may be limited, some adapted SD approaches have focused on the qualitative modelling aspects sans any simulation modelling while still arriving at insights (Wolstenholme, 1985; Coyle, 2000; Forrest, 2009).

The researcher believes that a sound application of SD necessitates both its qualitative and quantitative components. A varying degree of importance and weighting of each component needs to be allowed depending on the structural level of complexity of the system (Luna-Reyes and Andersen, 2003).

For simple systems that exhibit complex behaviour, there is at least equal importance of both the qualitative and quantitative components of SD because the insights gained from quantitative simulation could not be easily achieved by solely relying on the qualitative aspects of SD. For the complex systems, the qualitative modelling aspects carry greater importance as they help adjust and readjust the mental models and thereby narrow the quantitative modelling effort.

3.1.3 SD in the Learning Context

SD modelling builds on our understanding of the problem and data to test intended strategies or policies for achieving the desired outcome. Lessons learnt from SD modelling often result in better-informed decisions and actions for that outcome. However, SD modelling in the context of learning whether individual or organisational, is more than a testing ground for ideas; it can be seen as a catalyst for learning by helping restructure the context of a problem and even the mental models or our understanding of the system (Sterman, 2000).

This confluence between goal and method can be perhaps best described by highlighting the single-loop, double-loop and triple-loop learning in an organisational setting (Radzicki, 2003; Barbat et al., 2011; Wang and Ahmed, 2013) as depicted in Figure 3.3 on page 41:

Single-loop learning involves monitoring an outcome and adjusting processes accordingly, e.g. sales figures for a product are down, the management responds by running a promotion,

Double-loop learning involves looking at the outcome from a higher order, e.g. the management realises that the reason that demand for this product is down is that it is becoming superceded, the promotion is shifted to a different product to drive more revenue.

Triple-loop learning, is yet of a higher order whereby reflection about learning occurs, often gaining insights from a much broader perspective; perhaps the real
problem is not in the sales figures but about failing to realise a market shift due to emerging technologies.

The use of SD modelling as a research methodology forms part of the learning context albeit with a slight distinction. The learning occurs in the mind of the researcher, not of the major stakeholders. However, insights gained from applying SD to the ELV recycling industry may still be useful to the industry stakeholders.

3.1.4 Adapted Approach to SD

Acknowledging the importance of stakeholder involvement in the development of grounded SD models*, several SD methods were investigated such as Group Model Building (Vennix, 1996), Learning Labs (Maani and Cavana, 2007), and Collaborative Conceptual Modelling (Newell and Proust, 2012). A need to adapt the SD approach became evident from the early days of the application considering the context of research, literature gaps, a large number of stakeholders and that a significant amount of effort and time spent with the stakeholders would have been required to create grounded SD models. The research approach builds on the stakeholder knowledge and perspectives to help construct grounded conceptual and simulation models.

After initially following the Modeling Process (Sterman, 2000), the approach was adapted as follows:

1. a methodological adjustment to the stages which occurred as the modelling progressed resulting in a slightly revised process where information gathering and checking, as well as model testing, became inherent and central to this research (Figure 3.4 on page 42).

2. incorporation of Stakeholder Interviews (SI), Qualitative Data Analysis (QDA) and Scenario Planning (SP) to collect information and data and to analyse and check qualitative data for SD model development.

Furthermore and during the SD model development, other literature gaps (i.e. premises size changes, material composition and revenue of Australian ELVs) were identified that necessitated spin-off or supporting studies.

In effect, the followed process began with a system exploration stage through SI, then using QDA to analyse the interview data and extract variables and influences. Conceptual and simulation models were created and reworked as more

* A grounded model is built based on stakeholder perspectives (either through consensus or aggregation) and reported flows of materials or information.
Figure 3.3: Triple-loop Learning and SD Modelling
adapted from (Sterman, 2000; Radzicki, 2003; Barbat et al., 2011; Wang and Ahmed, 2013)
Figure 3.4: A revised SD Modelling or Research Approach

information was gathered and integrated and the problem definition was refined. Then an SP workshop with a group of stakeholders was conducted to identify the major uncertainties and trends defining future scenarios. Additional studies were carried out to address gaps in data for variables in the simulation SD model.

3.2 Stakeholders Interviews

Published Work†

A semi-structured interview format was chosen to gain an understanding of the:

- flows of materials within the system (sourcing of ELVs/materials, sale of parts/materials, disposal of waste),

- decision factors or business policies influencing these flows (company, industry, government), and

- business characteristics of automotive recyclers (e.g. workforce size, years in business).

3.2. STAKEHOLDERS INTERVIEWS

The information gathered from the interviews was intended to help develop the structures of the SD models (Stocks and Flows) and to identify the areas of concern, for the stakeholders, within the system.

3.2.1 Interview Design

With the aim to increase the conversion rate for the voluntary one-on-one interviews, it was decided to keep the interview time to less than an hour. For this reason, it was infeasible to include any SD modelling activity. The interview questions were chosen to keep the participant interested (Schein, 1999) while providing with the vital information about the state of affairs in the automotive recycling business (Table 3.1 on page 44 for a summary, Appendix C for the list of questions). The questions were designed with automotive dismantlers/parts recyclers in mind but can be adapted to other types of stakeholders such as scrap metal recyclers and car auction houses. General qualitative research guidelines helped in devising the interview format (Neuman, 2006; Richards and Morse, 2007). Two mock-up interviews were conducted with colleagues for practice and refinement.

3.2.2 Data Collection

The researcher approached via email, telephone or in person 27 automotive recyclers as well as three automotive industry associations and three car auction houses. These were identified through a public registry of automotive recyclers (APRAA, 2007), the Yellow Pages and personal contacts in the industry.

Each of the business entities approached was provided with an information sheet about this project. To help increase the conversion rate, the respondents were free to set the interview dates and times. In total, fourteen interviews were conducted, out of which three were non-structured as the interviewees were industry associations and law enforcement representatives.

Between December 2010 and March 2011, the researcher travelled to each respondent’s workplace to conduct the interviews.

Most of the interviews were audio-recorded using a digital recorder after receiving consent from the interviewees with five of them opting out. Interviewees

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Refer to Table 3.2 on page 46 for a summary of participants’ grouping and location.
### General Questions

- Challenges facing the industry and business [Industry Challenges, Policy Challenges, Business Challenges].
- Outlook of the industry and business [Industry Outlook, Business Outlook].
- [Effects of affordability of new cars on the automotive recycling industry and business].
- [Effects of emerging automotive fuel technologies (such as hybrids, diesels, Liquid Petroleum Gas, etc.) on industry and business].
- [Effects of possible policies on industry and business].

### Business Focused Questions

- Business characteristics [Years in business, Links with industry association, Premises, Specialisation, Workforce size, Turnover, Business hours].
- Business input [Factors considered when sourcing ELVs, Sources of ELVs]. Business operations [Handling of incoming ELVs, Handling of hazardous waste, Factors for deciding on parts suitability for resale/recycling, Stock labelling, Use of ICT].
- Business output [Types of customers/revenue streams, Export streams].

**Table 3.1: An Overview of Interview Questions and [Themes]**
3.2. STAKEHOLDERS INTERVIEWS

were asked to sign a disclaimer form as per the university research requirements.

Post-interviews, backup copies of the digital audio recordings were made. Each taped interview was then transcribed into a text file along with its field notes. For those interviews where taping was not consented to, field observations were transcribed from handwritten notes. Finally, the transcripts were imported into QSR NVivo 9, a qualitative research software to facilitate the analysis.

Because of the semi-structured nature of the interviews, the participants were frequently prompted for more information and explanation which meant that for some straightforward questions (e.g. sources of ELVs), the answers extended into long passages of text. Participants often gave details more relevant to a different question. As a result, information relating to a specific question was scattered across several parts of the transcript.

From the above, it became apparent that word-for-word linear transcriptions of the audio recordings could later complicate the data analysis. Hence, interviews were transcribed in a non-linear manner. When a piece of information is more relevant to a different question than the one asked, it gets transcribed into the most relevant question or section. This approach prolonged the transcription process but simplified the analysis process because it enabled all the relating information to a single question to be quickly reviewed.

3.2.3 Data Analysis

Once the transcription of the interviews was complete, came the process of coding (Richards, 2009). The answers were first coded or grouped by interview questions or themes. Each question represented a node of information through which can be viewed the answers from all respondents to that particular question. For every node, a memo was created and linked to that node.

3.2.4 Qualitative Model Building

To help develop the conceptual models the following points were addressed sequentially: Theme, Observation, Why is this interesting?, Relevance to SD model, Emerging Theory, Missing Data, Identified Variables, and Causal Links. For better clarity and ease of access, the memo was formatted as a horizontal table (Appendix D) with each point in its column. Below are these headings detailed along with the reiterative process followed to address them:

- Theme: Code the question being treated. E.g." Workforce".
<table>
<thead>
<tr>
<th>Stakeholder Group</th>
<th>Number of Interviews and Location (State)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automotive Recyclers</td>
<td>5 in Victoria 3 in South Australia 1 in New South Wales</td>
<td>Interviews followed planned questions.</td>
</tr>
<tr>
<td>Auction Houses</td>
<td>2 in Victoria</td>
<td>Interviews used part of the planned questions to gather information about the flow of damaged cars at auctions.</td>
</tr>
<tr>
<td>Industry Associations</td>
<td>1 in Victoria 1 in South Australia</td>
<td>Unstructured Interviews to gather information on the associations’ role in the system. Only notes were taken.</td>
</tr>
<tr>
<td>Law Enforcement</td>
<td>Victoria</td>
<td>Unstructured interview to gather information the law enforcement agency’s role within the system. Only notes were taken.</td>
</tr>
</tbody>
</table>

Table 3.2: Interview Participants - Groups and Locations
• Observation: Summarise the responses systemically. Provide an analysis of the findings along with any relevant ideas. This reiterative process is as follows:

1. Review the answers given by all respondents.
2. Identify specific factors (codes) that can capture the information. E.g. for “Workforce”: “Workforce Size”, “Workforce Growth”, “Improve Skill Level”, “Causes for Workforce Size Changes”, and “Labour Cost”.
3. Identify the sub-codes for every code. Count how many respondents answered each sub-code. E.g. for “Improve Skill Level”: hire skilled workers (1 participant mentioned this), train current workforce (2), and dismiss unskilled (2).
4. Compare, analyse and discuss the findings for every code. E.g. for Workforce Size: ”There first seems to be a correlation between the workforce size and the annual turnover volumes of ELVs. The UPI group with an average of 22 workers turns over 5100 ELVs per year, whereas for the SP with of 12 workers turning over 482 ELVs per year. It must be noted, however, that the dismantling activity is prominent in the SP group, whereas for the UPI group the activity is minimal and relates mostly to the treatment of incoming ELVs (e.g. draining fluids, removal of batteries)”.

• Why is this interesting?: Reflect on the question and the resulting analysis from a higher perspective. E.g. ”This question was asked not just to collect raw workforce data about businesses but also to try to understand the underlying mental models that drive this factor and in what ways. It was found that auto recyclers control their workforce size and skill level depending on their business financial situation (e.g. business is growing) and their drive to increase efficiency (achieve higher turnover with same workforce size, or maintain turnover while reducing workforce size)”.

• Relevance to SD model: Indicate how such findings can be used when constructing an SD model focused on this area. E.g. “Identification of several causal links between workforce size/cost/skill level and business profits/turnover/optimisation”.

• Emerging theory: Indicate the theory or general observation which can be grounded in the data. E.g. “Automotive recycling is a labour intensive
operation. Operators that are able to adapt their workforce (whether size, cost, skill level) to changes are more likely to stay longer in business”.

- Missing data: Highlight any data that may be collected and studied to support further the theory that emerged. E.g.”A wider survey of automotive recyclers to study the link between historical changes in their workforce size and skill level and their business turnover”.

- Identified variables: Using the codes identified earlier and from insights gained from this analysis, list the variables or factors that could be used in an SD simulation model to represent dynamic changes to this area. Indicate the unit where possible. Not all codes may entail sub-codes. Not all identified in the Observation step will make it to this list. Some codes may need to be renamed. New codes may emerge. E.g. “Workforce Size (Integer), Labour Cost ($/hour), Skilled Labour (Percentage), Unskilled Labour (Integer), Workforce Efficiency or Productivity (Business Turnover/Workforce Size)”.

- Causal links: From the list of variables identified in this area and other areas (previous or later questions), indicate their relationships using a simple one-way causality notation. Vennix recommendations for building causal diagrams during interviews were followed to suit this purpose (Vennix, 1996):

1. Pick an identified variable to start with.

2. Identify the variables that affect the chosen variable with the polarity. Previously unknown variables could emerge. In this case, add them to the identified variables list. Variables names may need to be revised.

3. Identify variables influenced by the variable with polarity where possible. Previously unknown variables could emerge. In this case, add to the identified variables list. Variables names may need to be revised.

4. Verify each causality link by comparing with transcripts:

   Workforce Size (+) → Labour Cost,
   Labour Cost (-) → Business Profits,
   Labour Cost (+) → Operations Optimisation,
   Business Turnover (+) → Workforce Size,
   Operations Optimisation (+) → Workforce Skill Level,
   Workforce Skill Level (+) → Workforce Efficiency,
   Workforce Efficiency (-) → Workforce Size,
   ...
3.2. STAKEHOLDERS INTERVIEWS

Workforce Efficiency (-) → Operations Optimisation

• Having identified the factors and causality links, construct an influence diagram for each question/focus area. During the diagramming process, variable names and causalities may need to be revised (while still ensuring validity with interview data). In several themes, a sufficient number of causal links was identified to form causal loops. A causal loop feedback could be negative or positive. The former is referred to as balancing (using a B in the CLD) and indicates a limit-seeking behaviour. The latter indicates a reinforcing behaviour (using a R in the CLD) whether the net effect is accelerated increase or decline (Sterman, 2000). Arrows around the B or R symbols indicate the directionality of the overall loop. A CLD of the workforce dynamics at automotive recyclers based on this process is shown in Figure 3.5 on page 50 and articulated below:

“As Business Turnover increases, auto recyclers increase their Workforce Size to keep up with the increased workload. Labour Cost is one of the main costing factors that affect auto recyclers’ profitability. As costs grow, auto recyclers tend to look for ways to optimise their business operations. They do so by adjusting their Workforce Skill Level to maximise the efficiency of their workforce. This includes hiring new skilled workers, retraining current workers, or dismissing unskilled workers. As a result, their Workforce Size dynamically changes. With the exception of a recycler who has been in business for less than 2 years, all other recyclers have indicated that their workforce size is constantly changing”. This dynamic hypothesis highlights the importance of the workforce factor which now can be seen as a dynamic variable with known causes and influences. It is now possible to construct a first-cut SFD that can further be refined (Figure 3.6 on page 50).

It is worthwhile to emphasise the reiterative nature of creating CLDs and SFDs from the emerging variables and causal links. As diagrams are created, the variables names and definitions may need to be changed. These changes, in turn, force a revision of the causal relationships as well as checking conformity with the observations made and the interview data.

It is also worth mentioning that some themes did not result in identifying new variables or causal links. For example: “Handling of Incoming ELVs”, “Industry Challenges” and “Industry Outlook” themes.
CHAPTER 3. RESEARCH METHODOLOGY

Figure 3.5: A Causal Loop Diagram of the Workforce Dynamics for the Australian Automotive Recyclers

Figure 3.6: A First Cut Stock and Flow Diagram of the Workforce Dynamics for the Australian Automotive Recyclers
3.2.5 Sourcing and Estimating Quantitative Data

The next stage in this application of SD is model formulation after having analysed the results from the model conceptualisation stage. Having started with an overall problem definition, that of the environmental concerns about the industry practice, it has now arrived at those five problematic areas. Each area can be viewed as a dynamic problem affecting both the auto recycling business and industry. It is important to note that these areas can also be viewed as part of the problems or challenges facing the industry. It is also worthwhile emphasising that these areas may not represent all the issues facing the industry, but only the ones emerging from this process.

For each area, a problem definition needs to be reached, data collection and modelling need to be conducted, and intervention strategies need to be identified, modelled and assessed.

In keeping with the grounded nature of this inquiry, the stakeholders in SD model formulation was deemed necessary. The proposed participatory procedure follows borrowed elements from GMB, Learning Labs and Participatory Workshops guidelines.

3.2.6 On Model Validation

SD model validation or verification is a continuous process of testing and building confidence in the SD model (Sterman, 2000). It is not an activity undertaken at the end of the modelling process but instead built into it. The validation for this SD model adheres to this principle in two ways:

- The first is through grounding the model in interview data which covers several aspects:
  
  - variable naming: stock and variable names use industry terminology or terms used by the stakeholders, e.g. Backyarders, ELVs in Yard, Dismantle, Sell Parts.
  
  - variables linking: relations between variables, as well as flows between stocks rely on interview data.
  
  - variable initial values: values used in the models rely on data that was either sourced from industry reports/interview/research data or estimated from secondary sources.

§the issue gets redefined subsequently as industry sustainability
– variable formulations: devising the formulae involves an extensive analysis of industry data using regression, comparative, inductive, and deductive analyses. It also requires multiple iterations of the model to test and refine the variables formulas to optimise the output against available data.

- The second path is by subjecting the model to shock values to gauge the behaviour, e.g. artificially raise the cost per square metres for the premises to check if the rate of growth slows down and shrinkage occurs. Because there are more than dozen variables that could be subjected to this treatment and the non-linearity of several of these variables and linked variable, a compounded test of variable shocks is an impractical pursuit, and hence only one variable is tested at a time within the confines of each model sector.

It is crucial to point out that, building on the previous two points, instead of simply having model validation conducted at the end of the modelling stage (i.e. while aiming to fit model data to real data), the process is built-in and relies on logic validation against the analysed qualitative data. In this adaptation and application of SD, the model is serving as a representation of collated and analysed stakeholder perspectives. The testing centres on checking whether these views can be validated logically. If the simulation model output conflicts with the real data, then -apart from the model being inaccurate which is a fundamental assumption, either the perspectives may be assumed as flawed, or the real data as inaccurate. The agreement of the SD model output with real data becomes about matching trends or behaviours (i.e. increase/decrease, limiting), not re-tracing real data. The latter being subjective and may be re-interpreted through varying and opposing mental models (Sterman, 2000).

On a related note, data fitting as form of model testing is perhaps better suited for situations where the main goal is proving that the model matches the real-world data to improve confidence in the model (Zagonel and Corbet, 2006). To help better illustrate, a traditional SD approach follows this path: explore a problem or system, identify most important metric or variable, source or collect data, analyse the data to find a matching SD model archetype, then using that archetype identify the variables and relationships that could be influencing that variable, develop a simulation model and validate it against the data. While much has been achieved using this method, and the exploration is valid especially for systems where the stakeholders pursue a common goal or interest, the approach becomes problematic were the stakeholders have different goals altogether (Ven-
In effect, asking a dozen of stakeholders for the elements influencing the variables that the modeller thinks are important will likely result in contrasted and perhaps contradictory responses. It represents a whole new challenge considering that few of the views are scientific (some may be based on single anecdotes). Instead of simply taking the stakeholder responses at face value and building simulation models that may be inaccurate or irrelevant, and to overcome the limitation of the traditional SD approach, the researcher took an open view to the method. Ultimately, the main focus is to transpose in a structured and clear manner the views of stakeholders into a grounded simulation model which would provide a testbed for various policy scenarios.

3.3 Scenario Planning Workshop

Published Work*

SP is a method, an interactive strategy-planning process used to think about the future, usually over a time horizon of a few years to a decade. SP involves the stakeholders in a workshop setting identifying plausible alternative futures under a driving theme, how the industry or enterprise might be impacted, and the type of policies or strategies that could be followed (Belt, 2004). Outside of the confines of SD, SP goes beyond just the identification step as it includes policy design, implementation and monitoring (Heijden, 2011). In this application, SP is structured around identifying the key trends and uncertainties that have the potential to impact the industry.

The process results in a set of qualitative data which can then be used to refine the SD models by subjecting them to the scenarios, effects and policy responses (Schoemaker, 1993). The SP workshop helps identify:

1. the trends, driving forces and impact: trends are long-term sequential patterns of change in factors that influence the business and the industry. The driving forces underpin and shape the trend, while impact designates the effect of the trend on the industry or enterprise. For example, the growing exports of old or damaged vehicles (trend) caused by the rising perceived

value of old vehicles in overseas markets (driving force) are affecting the supply of old or damaged vehicles (effect).

2. major uncertainties and associated uncertainty level: uncertainties are future unpredictable elements that may influence the industry or enterprise — The critical difference between a trend and uncertainty is in how ‘unsure’ we are about how an element might evolve. A trend may be seen as an uncertainty if for example there are opposing (or hard to determine) driving forces at play such as the results of elections. The level of uncertainty combined with potential impact helps determine the importance of such uncertainty. The best case and worst case of the most significant trend and uncertainty are then combined to form a set of four plausible futures or scenarios.

3. the effects of the scenarios on the industry and enterprise.

4. the industry policy or business strategy responses under each of the scenarios.

### 3.3.1 Workshop Design and Challenges

SP workshops typically span several sessions over days (and even weeks), most of which involve lengthy group activities and discussions (Belt, 2004; Heijden, 2011). This workshop was confined to a single afternoon due to the availability constraints of the participants. As a result, four workshop design challenges were encountered:

1. First challenge: getting the major elements of an SP workshop to fit into a single three-hour session from a modelling perspective.

2. Second challenge was simplifying the activities to a point where it would be easy to explain by the facilitators, easy to follow by the participants as not to cause confusion or misunderstanding.

3. Third challenge: deciding on a medium and a mechanism to gather opinions and ideas from the participants that would permit the facilitators to check whether the instructions are followed and whether the activity is delivering the intended outcomes. Part of this challenge was deciding on a room layout that would permit the movement of the facilitators among the participants.
4. Fourth challenge: keeping the process under control while managing conflict that could arise during the workshop as a result of differing views among the participants. Typical SP workshops rely on consensus building which is difficult to achieve within a few hours.

The first challenge was tackled by adopting the ideology of focusing on the most significant parts of SP from a modelling perspective. The previously identified five focus areas and their underlying theme “Sustainability of the auto recycling industry in 2025 and beyond” were used to guide the discussions, with this discounting the need to deliberate and agree on a theme for the SP activity (Heijden, 2011). The choice of the focus areas and the theme was verified by surveying the participants before and after the workshop.

Furthermore, the activities were designed and planned around being able to identify model relevant scenarios and their influences on model areas. Each activity began with an overview of its aims, the jargon, and an example. The process would then be explained using simple slides with actual pictures of the tools (pens and multi-colour sticky notes). A simple run-in example was also demonstrated during the introduction to help bring the participants up to speed with the process. The required steps were also listed on the worksheets (Appendix G). The aim was to minimise the possibility of confusion about the procedure. Particularly useful to keep track of the workshop design process was an adapted 21-point checklist from Chambers (2002) including process recommendations from Kumar (2002) and Sims (2006).

In trying to address the second challenge regarding the SP process design, several trials runs, and refinements were conducted with colleagues before the workshop to ensure that the instructions were easy enough to follow as not to cause boredom (Vennix, 1996) and that the timing of each activity was adequate. It should be noted that the approach is biased towards maximum time use at the expense of subject depth.

To help overcome the third procedural challenge, small multi-colour sticky notes (35x48mm) were used. As facilitators, it was possible to establish, from a single glance at a group’s worksheet, whether the instructions were followed and that the noted opinions were ranked accordingly (i.e. using different colours). A voting round was implemented at the end of the group discussions to identify the most significant elements that can be used to achieve the intended outcome. The venue chairs and tables were arranged in a U-shape to allow for quick movement of the facilitators among participant groups (Chambers, 2002).
As for managing conflict, the fourth challenge, the participants were asked to note down differing opinions rather than verbally debating them. It was anticipated that the noted differing views could be clustered and treated accordingly at the end of each activity/voting round.

3.3.2 Process

Together with Charles Featherson, the researcher facilitated the three-hour workshop on 18 October 2012 at a meeting venue in Sydney paid for by NSW MTAA. The workshop ran ten minutes overtime as a result of discussions taking longer than anticipated (for the SP workshop timeline refer to Figure 3.7 on page 57). Eleven participants from four states (NSW, VIC, QLD and SA) participated.

Nevertheless, there was a good overall representation of the industry: seven of the participants were auto recycling business owners/managers while the rest were representatives from state industry associations. The facilitators had to promote the communication process throughout and follow a strict time-keeping protocol to be able to get through all activities in time.

After delivering a presentation introducing key concepts and the SP aims and driving theme, the participants engaged in discussions first at pair level, then at a group level to identify: trends driving the auto recycling industry and the uncertainties in the industrial environment. Then participants were asked to decide on the most significant trend and uncertainty that would be used to construct the scenarios.

During the 15-minute break to sort and analyse the discussed trends and uncertainties to arrive at the two main dimensions of the scenarios. The participants then split into groups/pairs each assigned a scenario (choosing a name for the scenario, discussing its effects on each focus area, and noting down the effects/observations).

3.3.3 Scenarios and SD Modelling

Once the collected SP worksheets and sticky notes were transcribed, a need arose for a detailed and clear procedure to apply the SP outcomes to the baseline SD model. Despite a decent coverage of applying scenarios to SD models, only overall approaches were found where the specific procedures are either overlooked or just assumed.

Within the realms of SD literature, Maani and Cavana (2007) adopt Schoe-
### 3.3. SCENARIO PLANNING WORKSHOP

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>13:00</td>
<td>Introduction – Background and process (20 minutes)</td>
</tr>
<tr>
<td>13:20</td>
<td>First Activity – Trends (20 minutes)</td>
</tr>
<tr>
<td>13:40</td>
<td>First Group Discussion (20 minutes)</td>
</tr>
<tr>
<td>14:00</td>
<td>Second Activity – Uncertainties (20 minutes)</td>
</tr>
<tr>
<td>14:20</td>
<td>Second Group Discussion (20 minutes)</td>
</tr>
<tr>
<td>14:40</td>
<td>Break (15 minutes)</td>
</tr>
<tr>
<td>14:55</td>
<td>Third Activity – Critical scenarios (20 minutes)</td>
</tr>
<tr>
<td>15:15</td>
<td>Fourth Activity – Strategies/Policies (20 minutes)</td>
</tr>
<tr>
<td>15:35</td>
<td>Group Discussion (20 minutes)</td>
</tr>
<tr>
<td>15:55</td>
<td>Wrap-up – Complete post-workshop questionnaire</td>
</tr>
<tr>
<td>16:00</td>
<td>Finish Line</td>
</tr>
</tbody>
</table>

Figure 3.7: An overview of the SP workshop timeline

![A snapshot from the SP workshop session](image.png)

Figure 3.8: A snapshot from the SP workshop session
maker’s(1993) list for building scenarios in their Systems Thinking and Modelling method but do not demonstrate the technical aspects of integrating the scenarios elements into the SD models. Heijden (2011), while using SD within the context of quantifying the scenarios and gaining a better understanding of the scenarios, does not detail the technical aspects either. It is a similar story with Belt (2004) who employs SD, scenarios and other approaches into her holistic Mediated Modeling paradigm. On a similar path, Alcamo (2008) in the Environmental Scenario Analysis approach borrows from SD to help quantify the scenarios but falls short of demonstrating the procedure.

More recently, Morecroft (2007) showcases how SD models can be run through different scenarios by changing variable values to challenge existing mental models of the users but does not touch upon revisiting and revising the structures that underpin the models. Stowell and Welch (2012) refer to the importance of modelling scenarios further reiterating Forrester’s emphasis on the usefulness of SD in decision making (Forrester, 1968) but do not provide the required how-to detail. Most relevant to this work, Schmitt Olabisi et al. (2010) present a real-world example of using scenarios insights in SD modelling in a participatory setting. Although the authors discuss interesting scenarios/models, they do not share sufficient detail on how the models were updated.

In broader non-SD contexts, still within the ST literature and relevant to this work, Williams and Hummelbrunner (2010) talk about a generic scenario technique adopted from Schwartz (1996) and Heijden (2011). They give an example of a real-world application that goes to the level of systemically assessing influences on factors and estimating trends. While acknowledging its practical implications, applying or transferring this technique into an SD context is not immediately apparent.

Furthermore, observing SD literature from a lateral viewpoint, the term scenario is often employed without universal adherence to a standard. ’Scenario’ appears under sensitivity analysis (e.g. Sterman (2000) and Morecroft (2007)) which describes the process of varying the values of the variables to gauge model response under different circumstances. By contrast, Forrest (1998) makes a theoretical distinction between sensitivity analysis and scenario analysis in SD and indicates that the latter should only be used when different futures are modelled through different structures.

Similarly, in this work, the researcher refers to futures determined through the SP workshop as scenarios. Moreover, while different futures may be modelled by changing the values of the variables, the researcher believes that a more consistent
and thorough grounded approach to SD modelling requires one to analyse and update the underlying models (CLDs and SFDs) where appropriate.

Building on the above, it is safe to deduce that while most SD literature is rich with overall guidelines and emphasising the importance of scenarios in modelling, there exists a possible gap in knowledge to develop scenario-based models using SP data explicitly. The QDA procedure used for handling SI data (Section 3.2.4 on page 45) to build the baseline SD model was adapted to overcome this gap.

3.3.4 SP Data Analysis Procedure

Step 1: For each scenario, create a tabulated memo of all areas of the model.

Step 2: Choose a scenario. Then for each model sector (rows), address the following headings (columns): Observation, Identified Variables, Causal Links Updates, CLD Polarities Updates, SFD Updates, Main Variables Behaviour, and Threads for Further Investigation. Below are the details of the headings and processes:

- Observation: Systemically summarise the transcribed notes. Provide an analysis of the current CLDs/SFDs. This reiterative process is as follows:
  1. Review and analyse the notes given by participants and existing CLDs/SFDs.
  2. Articulate the effect of the scenario on this area of the model.
  3. Analyse the ramifications of changes within this area to other areas of the model.

- Identified Variables: Add newly identified factors (with units) that can capture the changes.

- Causal Links Updates: From the list of variables identified in this area and the current CLDs indicate the updated relationships using a simple one-way causality notation. Use the approach presented in Section 3.2.3.

- CLD Updates: Shortlist the changes in the CLD and verify whether loop polarity is affected.

- SFD Updates: Shortlist the changes in the SFD (adding converters/flows/stocks, altering connectors, modifying values of transfers/flows, and/or updating the equations/values). Justifying the SFD Updates: Justify the choice of these particular SFD updates over others. Indicate other possible updates and the reasons for not choosing them.
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- Main Variables Behaviour: Estimate the trend (increase, decrease, level/no change) for each updated/new variable in the SFD variable. If needed, specify the characteristic of the trend (rebound, oscillation, exponential).

- Threads for Further Investigation: Note any observation or theory that could be tested when modelling.

Step 3: Update the CLDs and SFDs using the resulting information in Step 2.
Step 4: Repeat Steps 2 and 3 for all scenarios.

3.3.5 SP Workshop Surveys

Two surveys were conducted, one before and another after the SP workshop. Both surveys serve as:

- validation of the selection of the five areas of interest identified from the interviews
- validation of the suggested workshop theme “sustainability of the auto recycling business and industry”.
- data collection medium about the participants and their background.

The pre-workshop survey also serves as a precursor for participants on the topics that will be discussed during the workshop. The post-workshop survey allows the participant to provide further notes as well as a feedback channel on the workshop.

Each survey is described below, along with the data collection and analysis processes.

3.3.5.1 Pre Workshop Survey

The one-page survey (Appendix E) designed for a time-poor potential respondent, has three questions:

The first question asks that the driving theme and each area of interest to be ranked using a five-point Likert scale. The respondent is given the option to comment on each area and to add additional areas if needed. The second question asks whether the respondent has participated in a scenario planning-type workshop. The third and final question asks about the capacity of the respondent (auto recycler, industry association official, or other). In the case of
3.3. SCENARIO PLANNING WORKSHOP

the auto recycler, the respondent is asked to specify the state(s) their business operated in, how many years they have been in business, the number of employees, total premises area size, annual turnover, and the number of ELVs bought. In the case of the industry association official, the respondent was asked to specify the states.

The survey was emailed as a Word document to the organising committee a week ahead of the scheduled workshop date. The committee forwarded then forwarded the form to the potential participants. They were asked to read over the information sheet and complete the survey electronically. The survey was to be emailed back directly to the researcher. Out of the sixteen potential participants, only four returned their survey representing a 25% response rate. The information provided in these responses could be seen as promising because three of the respondents had not participated in the previous interviews, and hence their views serve as validation of the identified areas of interest. It must be noted that given the qualitative nature of the inquiry, these responses may be valued despite the low return number which from a statistical standpoint may be viewed as insufficient.

3.3.5.2 Post Workshop Survey

The two-page survey (Appendix F) covers six questions: The first question asks the participant to rank the driving theme and each area of interest to be ranked using a five-level Likert importance scale. The participant is given the option to comment on each area and to add additional areas if needed. In question 2, the respondent is asked to highlight the most significant area(s) that were inadequately addressed during the discussions of the workshop. The third question asks about the background of the participant (auto recycler, industry association official, or other). Question 4 uses a Likert scale in helping to identify the agreeableness of the participant on how well the main issues affecting the business/industry were addressed, and whether their understanding of the main issues affecting the industry changed. Question 5 again uses a Likert scale in seeking feedback on the workshop process, including time allocated to activities, time allocated to discussions, breadth of topics covered, depth of topics covered, clarity of the process, and the overall experience. The sixth question seeks input from the participant on workshop aspects they would like to see different if they were to participate again in a workshop of this type.

The survey forms were distributed to the participants there were present (11)
after the final discussion of the workshop. The completed forms were then collected.

Data Analysis:

Question 1: Responses for each area are then counted according to a converted Likert scale (4 for very important, 3 for important, 2 for fairly important, 1 for somewhat important, and 0 for not at all important). The values are aggregated. The aggregate scores are then translated back to importance levels. Comments are transcribed.

Question 2: Answers are transcribed.

Question 3: Responses for each group are counted.

Question 4: Responses for each area are then counted according to a converted Likert scale (2 for very satisfied, 1 for satisfied, 0 for neither, -1 for dissatisfied, and -2 for very dissatisfied). The values are aggregated. The aggregate scores are then translated back to importance levels. Comments are transcribed.

Question 5: Responses for each area are then counted according to a converted Likert scale (2 for Very satisfied, 1 for satisfied, 0 for neither, -1 for dissatisfied, and -2 for very dissatisfied). The values are aggregated. The aggregate scores are then translated back to importance levels. Comments are transcribed.

Question 6: Comments are transcribed.

For questions 1, 4 and 5 the aggregate scores are calculated as follows:

\[ \text{Aggregate Score} = \frac{\sum (n_i \times \alpha_i)}{N} \]

where

- \( n \) is the total number of responses for level (i)
- \( \alpha \) is the conversion coefficient for that level, and
- \( N \) is the total number of responses across all levels.

3.4 Methods for Additional Studies

This section presents the data collection and analysis methods for the aerial survey of ELV recyclers, the ELV dismantling trial and the lifecycle inventory study.

3.4.1 An Aerial Survey of Australian Automotive Recyclers

An analytical survey using Google Earth/Maps 6 year-worth of satellite imagery -2007 to 2013 was conducted covering 123 automotive recyclers across Australia which allowed to compute an average area size for a dismantler and growth over
3.4. METHODS FOR ADDITIONAL STUDIES

the period. This small longitudinal study represents a first of its kind for surveying premises area size of dismantlers. Using satellite imagery for surveys and data has been demonstrated as a reliable method (Yu and Gong, 2012; Taylor and Lovell, 2012).

The data collection method involves four reiterative steps:

- **Step one**: select a sample of automotive recyclers. The only selection criterion is that it must be or was a registered business - verified through the Australian Business Register (ABR), that advertised as an automotive (not truck or motorcycle) recycler. Several data sources were consulted: APRAA, ARA, Google search, and located by chance using Google Maps. All 58 automotive recyclers on APRAA list was added as they were spread over most states/territories. A random sample of 49 samples from ARA’s database was selected. The operators located through Google Earth were either neighbouring some sampled operators or in two particular instances, neither the APRAA/ARA listed them nor Google search returned any result for that specific postcode. The sample was supplemented by recyclers found when verifying the addresses of the initial sample. Google search typically often returned neighbouring or nearby automotive recyclers - mainly when the one searched for no longer operated.

- **Step two**: verify the number of sites or branches that each recycler had/has and whether the site location has changed. This process entails searching for the name of the recycler using white pages, accessing the recycler website -if it exists, looking up the recycler business/trading name history on the ABR (which could entail searching again using a previous or new name), and even using Google Earth’s street view feature to check business signs. In few cases, the recyclers had an adjacent lot accessible through the back end of their trading premises or had a nearby lot on the same street.

- **Step three**: measure the total area size of each of the sites, the area size of the yard where ELVs are stocked, a count of ELVs visible and whether they were stacked. This process relies on a Google Maps Area Calculator Tool (Daft Logic, 2013) which permits the superimposition of measurement markers onto the yard satellite imagery. Additional markers can be placed to create non-regular shapes, e.g. around buildings, main driveways. All visible land areas seen to stock ELVs are assumed part of the yard.

- **Step four**: collect historical changes by using Google Earth’s feature “Show
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<th>ARA</th>
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</tr>
</tbody>
</table>

Table 3.3: Aerial Surveyed Automotive Recyclers by State/Territory and by Source

Historical Imagery” to cycle through available satellite imagery between 2007 and 2013.

The reiterative aspect involved cases where a business ceased trading or relocated or where the most recent satellite imagery was blurred due to clouds/weather which made it impossible to count the ELVs in the yard. In these cases, the ELV count relied on imagery from an older date.

For each business the following data was collected:

- Total area size of all premises in square metres
- Total area size of all yards (excludes buildings/warehouses/customer parking)
- Number of ELVs that are visible in the most recent satellite imagery
- whether ELVs are stacked/partially stacked or not stacked
- Any notes on whether the business area size grew, shrunk, relocated or ceased trading. In the case of expansion/downsizing, the difference in area size square metres is estimated using the most recent satellite imagery.
3.4. METHODS FOR ADDITIONAL STUDIES

Figure 3.9: Aerial Surveyed Automotive Recyclers Approximate Location by Postcode

Figure 3.10: An Example of using daftlogic Google Maps Area Calculator
3.4.2 Material Composition and Revenue Potential of ELVs

Published Work†

Between January and March 2013, a dismantling trial of 1115 ELVs at a reputable automotive recycler in Melbourne was conducted to:

- help establish the current material composition of Australian ELVs, and
- assess the potential of the industry to adopt more substantial dismantling processes.

The following overview helps illustrate the processes involving the handling of these ELVs, their dismantling, and parts weighings.

ELVs specifically chosen for their parts value are sourced from salvage car auctions, direct from the public, used car dealers, local councils, and car towing service operators. Upon arriving into a holding yard, the ELVs are inspected, inventoried, and then moved into a processing hangar for depollution and removal of quality parts. Where applicable, fluids (e.g. coolant, hydraulic fluids, engine oil, gearbox and differential oils, and fuel) are drained while Air Conditioning (A/C) gas and Liquid Petroleum Gas (LPG) are extracted. The batteries, wheels/tyres, tow bars, and catalytic converters are also removed. Parts deemed to be in high demand, good condition, and high value are dismantled (e.g. engines, transmissions, door mirrors, audio equipment). These parts, including usable batteries and wheels/tyres, are tagged and warehoused for sale as quality used parts.

The ELVs are then placed into a sale yard where walk-in customers dismantle parts as required. The 650-ELV yard stock is rotated on a daily basis. Every day twenty ELVs that had been on display for ten weeks are replaced with newly acquired ones and moved to a dismantling hangar where an excavator-based Multi Dismantling Machine (MDM) is used to break them apart.

The components removed earlier during the depollution process and from the machine-based dismantling are grouped by rough metal composition, pressed into bales using a compactor, and then weighed on an industrial scale. Except for the left-over tyres that are disposed of through tyre recyclers for a fee, the bales are sold to their respective recycling markets including metal recyclers and catalytic converters recyclers.

3.4. METHODS FOR ADDITIONAL STUDIES

3.4.3 A GTG LCI of Machine-based Dismantling of ELVs

Published Work**

This study complements the previous one to check if the value-added activity of using an MDM is a better environmental alternative to the conventional process among metal recyclers - compacting, shredding and post-shredding processing for material recovery. To help answer this question a GTG LCI is carried out using data obtained from a second trial involving the same MDM. The results are then compared with normalised data obtained from literature on shredding and post-shredding material separation.

3.4.3.1 Scope, Motivation and Aim

Life Cycle Assessment (LCA) is a standard tool that can be used to calculate the environmental impact of a product or service over its lifetime. LCI is the data collection component of LCA that aims to provide a comprehensive breakdown of materials exchange with the environment (ISO, 2006). A GTG LCI is limited in

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scope to a single process in a chain, in this case, the machine-based dismantling of ELVs. Life cycle impact assessment (LCIA) utilises the results from the LCI to determine the environmental impacts grouped by categories. This analysis is limited in scope to the GTG LCI of MDM for ELV dismantling. The data and results presented here could be used in future comprehensive LCA studies on ELVs.

As previously discussed in Chapter 2, significant research has gone into the domain of ELV recycling, seen as an essential subset of the life cycle of vehicles due in part to the pollution potential of hazardous materials present in ELVs, and to the shift towards waste reduction and improving recycling.

Applying LCA to ELV processing using an MDM stemmed from the idea that this material/component segregation method is relatively new in the market and has not been researched before as communicated by the Australian representative of the Japanese MDM manufacturer. A question arose whether it is environmentally a better alternative to the current norm, which is compacting followed by shredding and further processing of shredder output.

LCA literature on ELV recycling is by no means scarce. Perhaps the most comprehensive and significant study to date remains that of Sawyer-Beaulieu (2009) assessing the environmental impacts of dismantling processes in Canada through a detailed GTG LCI. The case study findings suggest that enhancing the recovery and recycling of materials from complex products, such as automobiles, will likely not result from disassembling an item the way it was produced, but from optimising various unit processes that work together and exploiting hidden opportunities revealed through an LCA.

Jeong et al. (2007) apply LCA to the Korean ELV treatment system comparing the current norm of 78% recycling rate to further dismantling (85% recycling rate), and to further dismantling with energy recovery (95% recycling rate) finding that the latter is ecologically the best scenario.

Fonseca et al. (2013) determine that in the case of Portugal, the further dismantling of components for recycling and energy recovery is environmentally better than the landfilling of automotive shredder residue (ASR) - the current norm, and energy recovery without further dismantling.

Ciacci et al. (2010) focus on ASR processing in their LCA study comparing five scenarios (ASR landfilling, further metals recovery, ASR incineration with energy recovery, advanced material recovery followed by thermal treatment of ASR residue and feedstock recycling using gasification). The article finds that the latter two scenarios are better environmentally than the others and that they
can help achieve the European Union (EU) ELV recycling/recovery targets.

Ferrão et al. (2006) discuss various ASR existing and emerging mechanical and energy recovery technologies using European, US and Japanese ELVs scenarios using data from a real-world Portuguese shredding experiment. Their results indicate that ASR mechanical recovery and recycling approaches are promising for meeting EU recycling targets than energy recovery.

Amaral et al. (2006) use a System Dynamics model, though not fully shown or explained, to assess various strategies (further dismantling, ASR separation) for meeting the EU ELV recycling/recovery targets (Kanari et al., 2003). They complement the work of Ferrão et al. (2006) by concluding that the 2015 targets can only be possible with further dismantling despite ASR separation being cheaper. The authors suggest the simplification of material compositions for large automotive parts to facilitate removal and recycling.

More recently, Sakai et al. (2014) explore the ASR issue from an LCA perspective, among several issues related to ELVs, and stress on the need for more research to explore better processing and material recovery.

To summarise, more research is required in the area of ELV and LCA, particularly exploring the effectiveness and environmental impact of emerging dismantling technologies, such as using an MDM, as alternatives to the current norm. Tangent to this inquest comes the question of whether it is worthwhile investing in dismantling technologies as opposed to ASR processing technologies from an environmental standpoint.

3.4.3.2 The Process

The process of acquiring ELVs and reaching the MDM facility are explained in Section 3.4.2 on page 66 and highlighted in Figure 3.11 on page 67. The MDM facility is equipped with the following machinery:

- An MDM powered by a 4.2-litre turbo diesel engine rated at 74kW (ISO14396: 2002) that operates for about 10 hours per day, five days a week.

- A scrap metal hydraulic packer powered by a 45kW electric pump used when compacting separated metals into bales.

- Three 500mm 0.25 kW exhaust fans running during the operation of the MDM to expel the fumes outside the hangar.

Excluded from the study is an LPG-powered forklift used to bring the ELVs into the facility and take out the bales. The researcher assumes that its operation
is non-critical to the segregation process. The hangar does not have artificial lighting as it relies on natural light and lighting from the MDM.

Between April and June 2013, diesel and electricity consumption of the stand-alone facility were monitored and recorded. Data from the earlier study in the previous section that focused on input/output materials were used to construct a GTG LCI for the MDM process. The system boundary is shown in Figure 3.12.

A fuel emissions estimation method was used to calculate CO2 emissions from the MDM. The other emissions are deduced using an energy-based emission estimation technique for industrial diesel vehicles (stationary) assuming a 0.25 load factor (NPi, 2008). Water vapour is calculated using the balanced equation of approximated diesel combustion which is also used to verify the CO2 value: $4 \text{C}_{12}\text{H}_{23} + 71 \text{O}_2 \rightarrow 48 \text{CO}_2 + 46 \text{H}_2\text{O} + \text{energy}$.

To compare with shredding the rate of energy consumption per tonne processed is assumed as per the Canadian study (Sawyer-Beaulieu, 2009) and the calculated emissions are adjusted to Victoria’s greenhouse gas co-efficient of 1.37kg CO2e/kWh (ESC, 2014). The amount of consumed diesel is converted to its energy equivalent.
3.5 Ethical Considerations

The interview processes were approved under the Australian National University Human Ethics Protocol 2010/612. The protocol was then varied in 2012 to include a provision for the stakeholder workshop. One of the human ethics committee requirements is about the management of identifiable information. The researcher adhered to this requirement by solely asking for non-identifiable information. With quantitative data, only the averages or sums are presented.

Conclusions

This chapter presented the methodological framework of the research, the data collection and analysis methods that were followed. The next chapter presents the results and various findings from supporting studies that were carried to address literature gaps in the automotive recycling industry.
Chapter 4

Various Findings and Results

This chapter presents key findings and results from various studies conducted to address knowledge and literature gaps about the business and industry of automotive recycling in Australia. The chapter is placed ahead of the modelling results chapters because some of the findings and results were used to arrive at various assumptions and trends used in the SD model.

Section 4.1 summarises business characteristics and operation models of the Australian automotive dismantlers gathered during the semi-structured interviews.

Section 4.2 presents the results of the surveys conducted before and after the SP Workshop to validate the selection of the five areas of interest identified from the interviews as well as the suggested workshop theme “sustainability of the auto recycling business and industry”, and to collect descriptive data about the participants and their background.

Section 4.3 presents the findings from an aerial survey of 123 automotive recyclers using Google Earth to determine the average premises area size, overall area size change trend, and the ELV carrying capacity.

Section 4.4 details the result from a dismantling trial to determine the material composition and revenue potential of Australian ELVs.

Lastly, Section 4.5 presents a gate-to-gate life-cycle inventory (GTG LCI) of machine-based dismantling of ELVs to determine the environmental impact of using a machine-based dismantling in material recovery.
4.1 Automotive Recycling Industry Insights

Published Work*

This section focuses on the business characteristics (Section 4.1.1) and operations (Section 4.1.2) collected from eight automotive dismantlers in New South Wales (1), South Australia (3), and Victoria (4). In trying to understand the business characteristics, the interviewees were prompted for the number of years in operation, affiliation with industry associations if any, premises area size, workforce size, working hours, specialisation in segments of the parts market, and approximate annual turnover. As most of these factors vary over time, it was important to gather an understanding of the evolving of business. Thus, for some of these points, the interviewees were further prompted for trends and relative changes however due to time constraints and the commercial sensitivity of the information it was not possible to collect granular or detailed data.

To cover aspects of business operations, questions were also raised about inventory control (handling of incoming cars, use of labelling), the use of Information and Communications Technologies (ICT), and the handling of hazardous waste.

Section 4.1.2 presents a grouping of business models that emerged from the interviews. Each business model is supplemented with a Causal Loop Diagram that constitutes an impression of the factors. These CLDs represent early versions of the aggregate CLDs of the actual SD model detailed in the following chapter.

4.1.1 Business Characteristics

- Years in business: On average, the interviewed operators have been in business for 20.25 years (N = 8, SD = 9.94). They have well-established businesses with strong commercial presence and links with suppliers and customers. They are generally proud of their line of work and are always on the lookout for ways to improve their business. Most view their role as righteous to the environment and the public (i.e. extraction of hazardous materials and recovery of reusable parts).

- Affiliation with industry association: Seven out of the eight interviewed operators are members of their state’s automotive/motor trade association.

An interviewee expressed his dissatisfaction with the industry association he is a member of, regarding lack of campaigning against illegitimate operators. Another one sees the association meetings as an opportunity to voice concerns or to propose ideas that could be beneficial to all. Membership of an industry association is not compulsory by law. Those who are members link the non-members to illegal practice.

- Premises area size: On average, the area size of a dismantling business is 18,867sqm (N = 8, SD = 17,465) with four interviewees having two or more sites. Dismantlers, in general, require large premises. This need is due to the stocking system they use and the physical dimensions of cars.

- Workforce Size: Based on the collected data, each enterprise employs 14.6 workers (N = 8, SD = 6.6). However, it became evident during informal discussions with the interviewees after the conclusion of the recordings that most interviewees may have overstated the number of workers by including casual or trainee positions. Estimating that the over-reporting is in the order of 10%, the researcher, therefore, assumed that the average number of workers per enterprise is closer to thirteen. Most of the operators indicated that they decide to grow or shrink their workforce size depending on how well their business is performing. Labour cost varies depending on the function of the employee. Skilled mechanics and salespeople are well paid and represent a significant cost factor as well as an asset/investment for business operations.

- Working Hours and overtime: Six out of the eight interviewed operators open Monday to Friday, 9 am to 5 pm. Most view overtime labour as costly and therefore generally try to avoid it. However, dismantlers that rely more on another revenue stream such as mechanical repairs recognise the profit potential. They are more likely to allow overtime work as they justify and can afford the added labour costs. For these dismantlers, the revenue from parts/materials trade alone does not justify these added costs. The remaining two operate on all days to cater for the Do-It-Yourself clients who usually shop for parts on the weekend.

- Specialisation: Five out of the eight interviewed pursue an ELV-type specialisation that allows them to operate within specific market niches. Some, for example, specialise in a specific car make or model, e.g. Holden Commodore. Others may specialise in vehicles older than ten years or 4WD
or commercial vans, or even in a group of makes like all Japanese or all German. In addition to used parts trade, all interviewed dismantlers were found to engage in mechanical repairs and used car trade. In a couple of cases, mechanical repairs were the core business activity, while the used parts trade was merely supplemental.

- Annual Turnover: The average annual turnover is 2.5 Million Australian Dollars approximately based on information provided by two interviewees who agreed to share their figures. Concerning the number of ELV turnover, the mean is 1516 ELVs per year (N = 8, SD = 2396). It is worth noting that the sum of ELV turnovers reported in the interviews is 12,128 which corresponds to about 2% of the total ELVs in Australia.

The operators may be grouped according to the number of ELVs they handle per year. Small-scale (less than 300 ELVs), mid-range (300-2000 ELVs), and large-scale (more than 2000 ELVs). The interviewed automotive recyclers are spread across these groups: three small, three mid, and two large-scale.

### 4.1.2 Business Operations

- Handling of incoming cars: All interviewed dismantlers have well-established systems to manage incoming ELVs. The process includes the labelling of vehicles (creating a file for every ELV), testing (if drive-able), depollution (draining engine fluids, removal of batteries, tyres), and stocking the vehicle in the yard. A small-scale operator pointed that they sometimes do not ‘depollute’ a vehicle if they see a potential in it being sold as a cheap old car.

- Parts/ELV Labelling: All interviewed operators engage in some form of labelling (incoming ELVs stock, parts) for inventory control. The You-Pull-It type operators only label vehicles while parts stay on the vehicles until the customers remove them.

- Use of ICT: Seven out of the eight interviewees make use of ICT to help find potential stock in the market, manage incoming ELV stock (labelling, sorting), and manage dismantled parts stock and sales.

- Hazardous waste: All interviewees were aware of their local EPA requirements concerning the handling of hazardous materials. Batteries, drained fluids, and even air conditioning gas are collected then sold to their respective markets. Tyres were the only component that the operators had
to pay for their disposal. Two dismantlers have certified systems to capture leftover petrol and liquid petroleum gas (LPG) from ELVs then use them to power their business vehicles.

## 4.1.3 Business Models

Based on the characteristics and operations of the interviewed recyclers and field notes/observations, it emerged that an automotive recycler or dismantler could fall under one of three categories: small-scale, large scale, and mid-range. Each category is presented below along with their characteristics and CLDs of the primary material/decision flows and influences. All categories share a strategy of maximum revenue and profit. Competition within the industry exists as some operators specialise in the same makes/models or are in close vicinity of each other. External competition is predominantly with the backyarders at the point of supply of ELVs largely influencing the ELV purchase costs - an issue which will be explored further in the SD model in the following chapter.

It is worth noting that, compared with the aggregate conceptual model presented in the next chapter, these conceptual models represent a preliminary perspective that formed following the interviews with the stakeholders. This transient perspective is deemed a valuable insight because it explores an overlooked complexity in the automotive recycling industry and brings to light some vital business aspects and linkages overlooked in the literature.

### 4.1.3.1 Small-Scale Dismantlers

**Workforce size** less than five employees.

**Premises area size** less than 3000 sqm.

**Yard capacity** about 250 ELVs.

**Vehicle turnover** Slow, less than 300 ELVs per year, as some vehicles stay for months and even years before sold as scrap.

**Operations** ELV dismantling is a secondary business activity with revenue deriving from parts sales about 20% of the overall revenue. The mechanical repairs/parts replacement is considered the primary business activity deriving 80% of the overall revenue. The operator is less likely to invest in a stock control
software. Vehicles and parts are labelled using markers, and the information is handwritten in record books.

The dismantling activity is based on the customer demand for used parts. Parts that are in-demand are removed from the vehicle and stocked on the shelf. Most other parts stay on the ELV until a customer seeks them.

The clientele is the public coming through word of mouth and looking for a cheap replacement part for an old vehicle (typically 15-year old). The operator hence seeks similarly aged ELVs from auctions to fulfil that need. Due to premises size constraints, ELVs are sourced on a casual basis and only when the space permits (after clearing some of the older stock) and when the price is right for a vehicle that is in demand (usually a Holden Commodore, Ford Falcon, Toyota Corolla/Camry). Sale of older ELV stock as scrap metal only is encouraged when the yard holding capacity is full or when scrap steel prices increase.

Figure 4.1 on page 77 illustrates the key variables and loops dominating the business operations of the small-scale dismantlers.

4.1.3.2 Large-Scale Dismantlers

**Workforce size**  more than 15 employees.
CHAPTER 4. VARIOUS FINDINGS AND RESULTS

Premises area size  more than 10,000 sqm, often with multiple sites.

Yard capacity  from 600 ELVs,

Vehicle turnover  Quick, more than 2,000 ELVs per year, with an ELV only kept for 4-6 weeks to maximise use of space and revenue from the ELV occupying it.

Operations  ELV Dismantling is the core or main business activity with revenue stemming from both sale of parts and sale of scrap metal.

Vehicles and parts are labelled using barcodes. Every part may be traced to its originating ELV.

The dismantling activity main driver is the continuous revenue stream from the sale of used parts and scrap metal. This business model reflects a process driven business. High-value In-demand parts are removed from the vehicle and stocked on the shelf. Most other parts stay on the ELV unless a customer requires them.

The primary customers are independent mechanics and repair workshops, while the general public only makes a small proportion (10-20%).

The dismantler seeks ELVs from all makes/models even if the revenue potential from parts is low. Achieving minimal profit after the purchase/processing costs is sufficient. The ELVs are actively sourced daily via direct advertising to the public (e.g. bomb removal using contracted towing services) and from salvaged car auctions. ELVs are also sourced from car dealers wanting to clear their trade-in stock.

Figure 4.2 on page 79 illustrates the key variables and loops dominating the business operations of the large-scale dismantlers.

4.1.3.3  Mid-range Dismantlers

These dismantlers began small, achieved significant turnover growth and gained reputation by distinguishing themselves from the mainstream operators by either:

- Specialising in a particular make/model/year: by fulfilling a niche, targeting the premium end of the ELV market where the clients are willing to pay a premium for difficult-to-source used parts instead of brand new (Figure 4.3 on page 81), or
4.1. AUTOMOTIVE RECYCLING INDUSTRY INSIGHTS

Figure 4.2: A Causal Loop Diagram of Influences in the Operations of Large-Scale Recyclers

- Aligning the automotive recycling business with an automotive insurance company: by responding to the demand created by repairs authorised by/covered by insurance. This cooperation guarantees the operator a revenue stream. The operator acts as an agent on-demand sourcing ELVs from auctions and extracting the required parts which are then sent to the authorised repairers (Figure Figure 4.4 on page 81).

Although the variables and influences differ between these two subgroups, the business characteristics are almost identical.

**Workforce size**  5 to 15 employees, most less than 10.

**Premises area size**  about 4,000 sqm (1 acre), often with multiple sites.

**Yard capacity**  300 to 400 ELVs in the yard

**Vehicle turnover**  Average, 300-2000 ELVs per year, with the yard cleared once every few months to once a year.

**Operations**  Dismantling is a core business activity, but other services are also offered (e.g. mechanic, vehicle testing).
Revenue from parts sales makes at least 80\% of the overall revenue turnover. Vehicles and parts are labelled using barcodes. Every part may be traced to its originating ELV.

Some operators conduct vehicle testing or checks before dismantling to identify faulty parts to help minimise warranty claims.

The demand for premium used parts drives the sourcing and dismantling of ELVs. The demand for used parts fluctuates depending on the popularity of the car model/make/year.

Due to competition with the public/backyarders at the damaged car auctions for the same vehicle stock which is seen positively by some operators as potential demand for parts, the operator seeks ELVs from interstate and overseas to fulfil this demand.

Some dismantlers operate in an even more niche and premium market, that of cheaper alternatives to new parts for insurance-funded repairs. The focus of the operations becomes the on-demand sourcing of the appropriate ELVs (again from the damaged car auctions) and the dismantling of specific parts required for a vehicle repair under an insurance claim. The insurer is attempting to reduce the economic write-offs (damaged vehicles are written off because the repair cost is deemed too high) as well as the repair costs.

The costs of premises are perceived as a concern, but not a limiting factor for sourcing or getting rid of ELVs.

4.1.4 Summary

One of the early challenges of developing an SD model of the automotive recycling industry in Australia was to source relevant and concrete data about the typical enterprise (such as years in operation, workforce, annual turnover, sources of revenue along with historical trends) and the norms and processes being followed for ELV dismantling. In this section, a reference point was achieved for the quantitative variables while for the qualitative variables a snapshot of flows and influences was captured.

An unexpected and worthwhile outcome was the identification and categorisation of diverse business models defining different dismantling operations and ELV/financial turnover. The diversity of business models will be further emphasised in Section 7.1 of the discussions chapter.
4.1. AUTOMOTIVE RECYCLING INDUSTRY INSIGHTS

Figure 4.3: A Causal Loop Diagram of Mark Specialised Recyclers

Figure 4.4: A Causal Loop Diagram of Insurance-aligned Recyclers
CHAPTER 4. VARIOUS FINDINGS AND RESULTS

4.2 SP Workshop Surveys

This section presents the results from the two surveys conducted before and after the SP workshop. For each survey, the results are presented and analysed sorted by the question.

4.2.1 Pre Workshop Survey

- Question 1: Qualification of the workshop theme and areas of interest importance level (Table 4.1 on page 83). The respondents regard all these themes as important. No other themes or new areas of interest are introduced.

- Question 2: Previous involvement in an SP workshop. Two survey respondents participated in an SP workshop before.

- Question 3: Stakeholder group, location operator business characteristics (where applicable). Three of the respondents are auto recyclers located in NSW. The fourth respondent is an industry association representative from SA. The three auto recyclers completed most of the fields about their business, the aggregate values are summarised in Table 4.2 on page 83.

4.2.2 Post Workshop Results

- Question 1: Ranking of the workshop theme and areas of interest (Table 4.3 on page 85). The number of responses (11). All the aggregate scores of the themes were at least perceived as important. Setting the workshop theme aside, and compared with other themes, the demand for used parts theme is perceived as most important, while the premises/land related theme is the least. No new themes were identified. Several comments were recorded that seem to either justify or explain the reason for a score or to emphasise the importance of the theme.

- Question 2: Themes that deserved more discussion (Table 4.4 on page 86).

- Question 3: Stakeholder group type. The number of responses (7). Three respondents identified themselves as auto recyclers, another three as an industry association representative. One respondent identified as “other” without further specification.
### 4.2. SP WORKSHOP SURVEYS

#### Table 4.1: Qualification of Theme Importance Level - Pre Workshop Survey

<table>
<thead>
<tr>
<th>Theme</th>
<th>Very Important</th>
<th>Important</th>
<th>Fairly Important</th>
<th>Somewhat Important</th>
<th>Aggregate Score (max 4.0)</th>
<th>Translated importance level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sustainability of the auto recycling business and industry</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4.0</td>
<td>Very Important</td>
</tr>
<tr>
<td>Supply of end of life vehicles (availability, purchase costs, etc.)</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>3.0</td>
<td>Important</td>
</tr>
<tr>
<td>Demand for used parts (revenue, client base, etc.)</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>3.5</td>
<td>Very Important to Important</td>
</tr>
<tr>
<td>Premises/land related (rental costs, location, etc.)</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>3.0</td>
<td>Important</td>
</tr>
<tr>
<td>Labour related (work laws, labour costs, etc.)</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>3.0</td>
<td>Important</td>
</tr>
<tr>
<td>Industry image and reputation</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>3.3</td>
<td>Important</td>
</tr>
</tbody>
</table>

#### Table 4.2: Operators Business Characteristics - Pre Workshop Survey

<table>
<thead>
<tr>
<th>Metric</th>
<th>Mean Value</th>
<th>N</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Years in business</td>
<td>33.33</td>
<td>3</td>
<td>15.28</td>
</tr>
<tr>
<td>Number of employees</td>
<td>22.00</td>
<td>3</td>
<td>4.36</td>
</tr>
<tr>
<td>Total area size of all premises in sqm</td>
<td>8733.33</td>
<td>3</td>
<td>3108.59</td>
</tr>
<tr>
<td>Turnover in $AU Millions</td>
<td>5.00</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Number of ELVs bought per year</td>
<td>1000</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 4.1: Qualification of Theme Importance Level - Pre Workshop Survey

Table 4.2: Operators Business Characteristics - Pre Workshop Survey
CHAPTER 4. VARIOUS FINDINGS AND RESULTS

- Question 4: Perception of participants on critical issues being addressed in the workshop, and whether their views have changed (Table 4.5 on page 87). The number of responses (9). The aggregate score of the first question indicates that the participants consider that the main issues have been addressed appropriately in the workshop. The score of the second question indicates that on average the participants perceive their understanding of the main issues as slightly changed. It is worthwhile to note that only two disagreed with the statement. No Strongly Disagree responses were recorded. A respondent noted in the comments: ”Good workshop structure”.

- Question 5: Participant satisfaction level with workshop aspects (Table 4.6 on page 87). The Number of responses (9). The scores indicate that the participants were generally satisfied with most aspects of the workshop. The depth of topics covered aspect received the lowest satisfaction score which resonates with the observation of the researcher that the discussion was rushed because of times constraints. Three comments were noted “Well put for a condensed meeting”, “Nice work”.

- Question 6: Recommendations and Suggestions. Two comments were noted. “More general discussion”, “Larger group” and “All great thanks”.

4.2.3 Key Observations

When comparing the aggregate scores for the themes in Question 1 between the two surveys, the differences are generally minor. Scores for three of the six themes are marginally less, but the translated importance level remains about the same. It is worth acknowledging that the small sample size for the first survey may limit the statistical significance of the conclusions that can be drawn.

However, it is reasonable to deduce that the themes that had emerged from interview data as well as the SP workshop theme “sustainability of the industry” could be considered as significant areas for the stakeholders in the automotive recycling industry. This observation is particularly significant given:

- the qualitative nature of this research,
- the subset of survey respondents and workshop participants were different from those interviewed,
### 4.2. SP WORKSHOP SURVEYS

<table>
<thead>
<tr>
<th>Theme</th>
<th>Importance Level Responses Count</th>
<th>Aggregate Score (max 4.0)</th>
<th>Translated Importance Level</th>
<th>Comments</th>
</tr>
</thead>
</table>
| Sustainability of the auto recycling business and industry           | 9  2  0  0  0                   | 3.8                       | Very Important to Important | - Recycling for our future
|                                                                      |                                  |                           |                             | - Recycling + stay green                                                                  |
| Supply of end of life vehicles (availability, purchase costs, etc.)  | 3  6  1  1  0                   | 3                         | Important                   | - A lot of grey area at the moment                                                        |
|                                                                      |                                  |                           |                             | - Will reduce purchase costs                                                              |
| Demand for used parts (revenue, client base, etc.)                  | 6  4  1  0  0                   | 3.5                       | Very Important to Important | - Or else we don’t have our business                                                       |
|                                                                      |                                  |                           |                             | - Stay green                                                                               |
| Premises/land related (rental costs, location, etc.)                | 3  4  1  2  1                   | 2.5                       | Important to Fairly Important| - We own our land (the participant scored the theme as not important at all)              |
| Labour related (work laws, labour costs, etc.)                      | 4  3  2  2  0                   | 2.8                       | Important to Fairly Important| - Keep profit or lose business                                                             |
|                                                                      |                                  |                           |                             | - Increase margins                                                                        |
| Industry image and reputation                                       | 5  4  2  0  0                   | 3.3                       | Important to Very Important  | - Improve image = Improve sales                                                            |
|                                                                      |                                  |                           |                             | - Needs work                                                                              |
| Other -                                                              | -  -  -  -  -                    | -                         | -                           | - Need to create ELV scheme                                                                |

Table 4.3: Qualification of Theme Importance Level - Post Workshop Survey
| Trends          | • Technology change  
|                | • Growth of unregulated operators |
| Uncertainties  | • Future policies  
|                | • Legislative responses |
| Scenarios      | • Backyarders need to be focused |
| Strategies     | • Better alliance with government agencies  
|                | • National licensing  
|                | • Improved compliance |

Table 4.4: Themes deserving more discussion - Post Workshop Survey
### 4.2. SP WORKSHOP SURVEYS

#### Agreeableness Level

<table>
<thead>
<tr>
<th>Question</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neither</th>
<th>Disagree</th>
<th>Aggregate Score (max 2.0)</th>
<th>Translated Agreeableness Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>The main issues affecting the business/industry were addressed appropriately</td>
<td>4</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>1.4</td>
<td>Agree to Strongly Agree</td>
</tr>
<tr>
<td>My understanding of the main issues affecting the industry has changed</td>
<td>0</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>0.2</td>
<td>Neither to Agree</td>
</tr>
</tbody>
</table>

Table 4.5: Main issues addressed and participant views changes - Post Workshop Survey

#### Satisfaction Level

<table>
<thead>
<tr>
<th>Workshop Aspect</th>
<th>Very Satisfied</th>
<th>Satisfied</th>
<th>Neither</th>
<th>Aggregate Score (max 2.0)</th>
<th>Translated Satisfaction Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time allocated to activities</td>
<td>0</td>
<td>8</td>
<td>1</td>
<td>0.9</td>
<td>Satisfied</td>
</tr>
<tr>
<td>Time allocated to discussions</td>
<td>0</td>
<td>7</td>
<td>2</td>
<td>0.8</td>
<td>Satisfied</td>
</tr>
<tr>
<td>Breadth of topics covered</td>
<td>0</td>
<td>8</td>
<td>1</td>
<td>0.9</td>
<td>Satisfied</td>
</tr>
<tr>
<td>Depth of topics covered</td>
<td>0</td>
<td>5</td>
<td>4</td>
<td>0.6</td>
<td>Satisfied</td>
</tr>
<tr>
<td>Clarity of procedures/activities</td>
<td>1</td>
<td>6</td>
<td>2</td>
<td>0.9</td>
<td>Satisfied</td>
</tr>
<tr>
<td>Overall experience</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>0.9</td>
<td>Satisfied</td>
</tr>
</tbody>
</table>

Table 4.6: Participant satisfaction with SP Workshop aspects - Post Workshop Survey
that no new or different themes of areas of focus emerged than those previously identified, and

- the responses about appropriately addressing the main issues (Question 5).

Therefore, it is safe to consider this observation as a confirmation or validation of the themes or focus areas on which modelling is focused.

From a methodological standpoint, the satisfaction levels and positive feedback (Question 6) suggest that the SP workshop process could be considered as an appropriate mechanism for facilitating relevant discussions around relevant topics. Furthermore, the responses about view changes (Question 5) suggest that an SP workshop in this short format could result in slight changes in the understanding of participants about critical topics. However, the nature of these changes and the degree in changes are not explored.

Based on all the above, the previously identified themes/areas of focus and the collected qualitative data from the SP workshop (i.e. the identified scenarios and effects) could be considered as valid.

4.3 An Aerial Survey of Australian Automotive Recyclers

This section presents the key findings of the aerial survey of Australian automotive recyclers conducted through Google Earth.

4.3.1 Survey Results

Between 2008 and 2013, it is noted that:

- Eleven grew the premises area size by 238.73% (SD = 56.80). The growths sum is the equivalent to the addition of 26.26 recycling premises.

- Eight shrunk the premises area size by 37.38% (SD = 16.81). This shrinkage is equivalent to the removal of 2.99 recycling premises.

- Three folded with the ABN no longer active.

Thus, the net change calculates as growth with the equivalent of 20.27 recycling premises.
4.3. AN AERIAL SURVEY OF AUSTRALIAN AUTOMOTIVE RECYCLERS

<table>
<thead>
<tr>
<th>Metric</th>
<th>Mean Value</th>
<th>Standard Deviation</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Premises Area Size in 2013 in sqm</td>
<td>8060</td>
<td>8870</td>
<td>123</td>
</tr>
<tr>
<td>Yard Area size in sqm</td>
<td>6386</td>
<td>8032</td>
<td>118</td>
</tr>
<tr>
<td>Visible ELVs in Yard</td>
<td>212</td>
<td>279</td>
<td>118</td>
</tr>
<tr>
<td>ELVs per 1000 sqm (Premises)</td>
<td>25</td>
<td>14</td>
<td>118</td>
</tr>
</tbody>
</table>

Table 4.7: Australian Automotive Recyclers - Aerial Survey

Given that the average premises area size is 8,060sqm, the net increase between 2008 and 2013 can be calculated as 163,376sqm.

Since the total area size of all surveyed dismantlers\(^1\) in 2013 can be calculated as 120x8,060sqm or 967,200sqm.

The total area size in 2008 would be the 2013 total minus the increase, or 967,200 - 163,376 = 803,824sqm.

Moreover, if all the 123 surveyed dismantlers were operating in 2008, the average premises area size can be calculated as 803,824sqm/120 = 6,535sqm.

Thus, the net increase in the premises area size over the 2008-2013 period can put as 23.36% or about 4.28% annual increase.

Finally, assuming that this rate of increase has been constant since 2003, the average area size of a dismantling business in 2003 would have been 5,300sqm approximately (Figure 4.5 on page 90).

Out of 118 dismantlers with visible yards, 44 representing 37.29% stacked ELVs at least partially. None of the expanding or shrinking enterprises engaged in ELV stacking.

4.3.2 Observations

The aerial survey indicates that despite the closure of some automotive recyclers and the shrinkage of several, the industry, as well as the common dismantling enterprise, continue to expand the premises area size which translated into an increase in the ELV carrying capacity.

Whilst noting that this survey falls short of identifying trends in the number of ELVs stocked in the yard and the duration of being kept, the sample indicates that current stocking practices may be far from efficient considering the low density

\(^1\)Excluding the three folded enterprises
of ELVs per 1000sqm and that more than of 62% of the surveyed dismantlers did not stack or pile ELVs.

These two observations highlight the need to explore the decision factors for premises area size growths over other ways to increase the carrying capacity.

### 4.4 Material Composition and Revenue Potential of ELVs

**Published Work**

Between January and March 2013, a dismantling trial of 1115 ELVs at a reputable automotive recycler in Melbourne was conducted to:

- help establish the current material composition of Australian ELVs, and
- assess the potential of the industry to adopt more substantial dismantling processes.

In this section, the results of the trial are presented and then contrasted with ELV dismantling data from Europe. The results are also aggregated over the

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4.4. MATERIAL COMPOSITION AND REVENUE POTENTIAL OF ELVS

Australian automotive fleet and highlight the revenue potential for automotive recyclers from adopting machine-based dismantling.

4.4.1 Results

The dismantling results are divided by the sample size (1115) to get an average of material weights and potential revenue per ELV (Figures 4.6 and 4.7 on page 93). The dollar value of the materials is calculated using the metal recycling prices in the state of Victoria as of March 2013. Furthermore, a conservative weight estimate is used for captured fluids of seventeen kilograms per ELV as no measurements are currently recorded. Recovered fuel is filtered and then consumed on-site in the forklifts and trucks on site. The remaining fluids sold to fluid recyclers at a negligible rate are therefore excluded from the revenue calculations.

On average, a processed ELV is 17.4 years old (Figure 4.8 on page 93 for the sample distribution). It has a kerb weight of 1275.92kg (median 1312, SD=251.33) of which, 138.13kg (10.83%) sells as used parts while the rest 1120.79kg is sold/disposed of as materials to scrap metal, tyres, battery and fluids recyclers. If that the plastic/glass content ends up in the landfill, the resulting overall reuse/recycling rate is 90.82%. The estimated recoverable metal content is 999.62kg (78.35%). As scrap, each ELV revenues AU$417.78.

The top ten makes (65%) of the sample - as presented in Figure 4.9 on page 93, positively correlate (0.84) with the top ten prevalent makes in the state of Victoria (based on cars made between 1971 and 2009 registered in Victoria). While the correlation is unintended, it could be attributed along with the relatively high re-use rate, to the business model sourcing the most popular makes to maximise revenue from the sale of used parts. From a scrap value perspective, the four most valuable components are catalytic converters (due to precious metals content like Platinum), wiring harness (Copper - Cu), radiators (Aluminium-Al and Cu), and alloy wheels (Al and Magnesium-Mg). Combined, they only make 2.46% (27.56kg) of the ELV weight as scrap materials weight but a substantial 25.21% (AU$105.34) in revenue.

Based on the results, it was found that an average Australian ELV is 30.63% heavier, 2.5 years older and contains 3.86% more recoverable metals than those in the UK (Eurostat, 2013). Moreover, it is at least possible at a small-scale to achieve a reuse/recycling rate in Australia similar to that in best-practice countries like Denmark (90.5%) (Weatherhead, 2005). These observations come as significant and unexpected.
Figure 4.6: Material/Component Composition per ELV in kg

A common practice in the industry with regards to ELV disposal as scrap metal is to sell highly valued components (i.e. manually removed batteries, catalytic converters, radiator, and alloy wheels) to supplement the low price paid by metal recyclers for the hulks, about AU$150 per ELV. Assuming that these components net AU$88.99 based on figures from the trial, the combined revenue per ELV would be AU$238.99. The revenue differential from having machine-based dismantling can be therefore put as AU$173.80 per ELV excluding machinery costs. Taking this figure further, if the top 20% of the industry (159 out of 793 auto recyclers) handling 80% of ELVs (488k out of 610k) was to adopt machine-based dismantling as a value-added activity, the annual industry revenue and profit could increase by AU$84.8 Million (7.71%) and AU$28.3 Million (11.6%) respectively based on 2011 industry data (IBISWorld, 2011). The proposed scenario is plausible regarding a daily throughput of about 13 ELVs per dismantler with sufficient spare processing capacity.

### 4.4.2 Limitations

It is important to note that the revenue estimate does not consider the fluctuations of scrap metals prices, as dictated by international prices and currency exchange rates, and the resulting damping of increased supply of segregated scrap metals on the local market.

Furthermore, the analysis excludes machinery costs and subsumes it as part of an ongoing investment that a relatively large recycling firm could make to maximise the revenue potential from an overlooked stream.
4.4. MATERIAL COMPOSITION AND REVENUE POTENTIAL OF ELVS93

Excluding revenue from parts sale and recycling of fluids. Tyre disposal requires payment to tyre recyclers.

Figure 4.7: Revenue in AU$ per ELV from Scrap Materials/Components

Figure 4.8: Dismantled ELVs Sample Distribution by Year of Manufacture

Figure 4.9: Top Ten Makes of the Dismantled ELVs Sample by Number of ELVs
There is scope to take this study further beyond the current limitations. First, the data collection process could cover a more extended period to identify trends in ELV composition. Secondly, the accuracy of ELV weight data could be improved by including the actual weight before to dismantling as opposed to kerb weight sourced from third-party databases. Lastly, further work is needed to assess the amount of recyclable materials (e.g. glass and plastics) that could be recovered during dismantling in the absence of legal requirements like in the EU (European Parliament, 2010).

4.4.3 Summary

A significant data gap on the material composition of Australian ELV was addressed by presenting the results of a first-in-kind dismantling trial, including age, weight, make, material/component composition, and revenue potential from the sale of materials as scrap. The results were with data from other countries. Also noted was the economic potential of machine-based dismantling, as a value-added activity, for auto recyclers seeking to maximise their revenue and profit potential.

4.5 A GTG LCI of Machine-based Dismantling of ELVs

Published Work

Having established in Section 4.4 that the use of an MDM improves the revenue potential from ELVs, it was necessary to check if the value-added activity is a better environmental alternative to the common process among metal recyclers - compacting, shredding and post shredding processing. To help answer this question a GTG LCI is applied using data obtained from another trial involving the same MDM. The results are then compared with normalised data obtained from literature on shredding and post shredding material separation.

4.5.1 Results

The MDM facility dismantled 1220 ELVs during the trial period (April to June 2013). The gross recyclable ferrous and non-ferrous metals outputs from the

---

MDM were 1219.54 tonnes or 999.62kg per ELV. The remainder 147.83 tonnes, or 117.16kg per ELV otherwise considered as ASR, were disposed of as industrial waste. Over the same period, the facility consumed 4.2klitres of diesel oil and 10.12MWh of electricity. The costs of diesel and electricity over the period came to approximately AU$8.60 per ELV (excluding wages, equipment maintenance, and location hire). Table 4.8 on the following page summarises the GTG LCI of the MDM trial. Worth noting that the CO2 emissions per ELV from operating the hydraulic compactor and the exhaust fans were higher than those coming from the MDM. These elevated levels could be attributed to the high CO2 emissions of energy production in Victoria due to the reliance on brown coal.

The results can now be compared to the normalised results from ELV shredding in the the Canadian study (Sawyer-Beaulieu, 2009). The aggregated results shown in Table 4.9 on page 97 suggest that MDM, although more energy intensive, comes out ahead of shredding in terms of costing ($8.50AU versus $11.47AU) and CO2-equivalent emissions. However, it is essential to treat this finding with caution because the scenario is specific to Victoria where the emissions of electrical equipment are high because of the coal-intensive electricity production. Consequently, the comparison will sway towards the electricity-intensive shredding process if greener energy sources power it. Conversely, if the hydraulic pumps/actuators of the MDM were electrically powered, the energy requirement will drop by about 70% from 36.91 kWh to about 11kWh because of the efficiency of electric motors (~95%) and the inefficiency of diesel engines (~25%) to convert energy. The net effect would be lower energy cost (about $7.20AU) but higher CO2-equivalent emissions (~26kg/ELV).

4.5.2 Limitations

There are several limitations to this GTG LCI. Firstly, the trial is limited to a single facility and operator. The quality of data could be improved if data from other facilities/regions are collected.

Secondly, the emission data is analytically deduced and not measured. This shortfall places the onus of results accuracy on the methods used to determine the emissions.

Thirdly, the trial does not consider the variation in emissions depending on the efficiency of the MDM process. With an hourly turnover of around two ELVs per hour, it is unclear whether increasing the rate of dismantling could help decrease
### Input

<table>
<thead>
<tr>
<th>Group</th>
<th>Inventory</th>
<th>Unit</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Materials</strong></td>
<td>ELV hulk</td>
<td>kg</td>
<td>1102.80</td>
</tr>
<tr>
<td><strong>Energy</strong></td>
<td>Electricity</td>
<td>kWh</td>
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<tr>
<td></td>
<td>Diesel</td>
<td>kg</td>
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</tr>
<tr>
<td><strong>Water</strong></td>
<td>Water</td>
<td>kg</td>
<td>:</td>
</tr>
</tbody>
</table>

### Output

<table>
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<tr>
<th>Group</th>
<th>Parameter</th>
<th>Unit</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Segregated Materials</strong></td>
<td>Fe - 81% pure approx.</td>
<td>kg</td>
<td>950.26</td>
</tr>
<tr>
<td></td>
<td>Cu - 50% pure approx.</td>
<td>kg</td>
<td>20.63</td>
</tr>
<tr>
<td></td>
<td>Al - 50% pure approx.</td>
<td>kg</td>
<td>15.34</td>
</tr>
<tr>
<td><strong>Emissions</strong></td>
<td>CO\textsubscript{2}-e</td>
<td>kg</td>
<td>11.36</td>
</tr>
<tr>
<td><strong>from Electricity</strong></td>
<td>CO\textsubscript{2}</td>
<td>kg</td>
<td>9.20</td>
</tr>
<tr>
<td></td>
<td>H\textsubscript{2}O Vapour</td>
<td>kg</td>
<td>3.62</td>
</tr>
<tr>
<td></td>
<td>CO</td>
<td>g</td>
<td>56.41</td>
</tr>
<tr>
<td></td>
<td>CH\textsubscript{2}O</td>
<td>g</td>
<td>2.46</td>
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<tr>
<td></td>
<td>NO\textsub{x}</td>
<td>g</td>
<td>134.66</td>
</tr>
<tr>
<td></td>
<td>Particulate matter smaller than 2.5\textmu m</td>
<td>g</td>
<td>10.01</td>
</tr>
<tr>
<td></td>
<td>Particulate matter smaller than 10\textmu m</td>
<td>g</td>
<td>10.92</td>
</tr>
<tr>
<td></td>
<td>Polycyclic aromatic hydrocarbons</td>
<td>mg</td>
<td>5.00</td>
</tr>
<tr>
<td></td>
<td>SO\textsub{2}</td>
<td>mg</td>
<td>72.79</td>
</tr>
<tr>
<td><strong>Solid Waste</strong></td>
<td>Total volatile organic compounds</td>
<td>g</td>
<td>12.74</td>
</tr>
<tr>
<td><strong>Waste</strong></td>
<td>Plastics, glass, foam, etc.</td>
<td>kg</td>
<td>117.16</td>
</tr>
</tbody>
</table>

Table 4.8: Gate-to-Gate Life-Cycle Inventory of Machine-based Dismantling
4.5. A GTG LCI OF MACHINE-BASED DISMANTLING OF ELVS

<table>
<thead>
<tr>
<th></th>
<th>Per 1.1t ELV</th>
<th>Unit</th>
<th>MDM</th>
<th>Shredding</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inputs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Energy</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity kWh</td>
<td>8.30</td>
<td>31.76</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diesel kWh equiv</td>
<td>36.91</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Water</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water kg</td>
<td>6.29</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Outputs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Emissions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂-e kg</td>
<td>22.83</td>
<td>43.51</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H₂O vapour kg</td>
<td>3.63</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.9: A Comparison of Energy/Emissions between MDM and Shredding

the emissions per ELV.

Fourthly, the human factors are assumed constant as the same operator operates the MDM throughout the trial. Closer examination of the process that the operator follows is required to ensure that the degree of dismantling and material separation are consistent. As for the comparative analysis to the shredding process, while helpful in terms of evaluating the environmental performance of the MDM, it remains theoretical since shredding facilities have different utilisation rates as they are used for a variety of feedstock (Sawyer-Beaulieu, 2009), as opposed to an MDM which is a specialised tool to dismantle ELVs. It is also worth mentioning that due to the project and logistical constraints, it was not possible to compare the output materials quality from the MDM to that of a shredder. Based on the last two points, there is scope for further research to answer these limitations.

4.5.3 Summary

The results of this GTG LCI suggest that MDM is an environmentally conscious alternative but only under the circumstances similar to those in Victoria where electricity production, and consequently energy-intensive shredding, has high levels of greenhouse gas emissions. Despite its limitations, the study provides a valuable insight into MDM’s environmental credentials.

Conclusions

This chapter presented the findings and results from five studies conducted to bridge knowledge and literature gaps in the Australian automotive recycling industry and business.

The business characteristics and operation models of the Australian automotive dismantlers were explored. In addition to the quantitative and qualitative
data crucial for the SD model development, it emerged that the dismantlers may be categorised by the business model which defines the dismantling operations and ELV/financial turnover.

The surveys conducted before and after the SP Workshop validated the selection of the five areas of interest, or modelling sectors, identified from the interviews as well as the suggested workshop theme “sustainability of the auto recycling business and industry”. They also helped qualify about the participants.

The aerial survey of automotive recyclers using Google Earth helped determine the average premises area size of a dismantler and the growth trend. It also provided a snapshot of the ELV carrying capacity per dismantler.

The results of two dismantling trials helped determine the material composition and revenue potential of Australian ELVs, and the environmental impact of using a machine-based dismantling in material recovery from ELVs.

In the following chapter, the SD model of ELV recycling is presented.
Chapter 5

A System Dynamics Model of ELV Recycling

This chapter presents the qualitative and simulation models of the automotive recycling industry in Australia.

The five areas of interest, identified mainly from the stakeholder interview data using the adapted approach, are ELV supply/demand and disposal, workforce, premises, parts sales, and industry image. The causality analysis and the respective influence or causal loop diagram of each area is presented in Section 5.1. The section concludes with an overview of the business, industry and policy challenges.

These five areas of interest are then viewed from an operational perspective internal to the industry and furthermore developed as sectors of an SD simulation model. Each sector is modelled using data sourced from industry reports, deduced from interpreting interview data or the supporting studies in Chapter 5, or estimated from one/combination of these sources. The SD model sectors and simulation results are described and explored in Section 5.2 while the model formulas are tabulated and described in Appendix H.

Lastly, Section 5.3 provides a summary of observations about the qualitative and simulation SD models.
5.1 Qualitative SD Model

Published Work*

In this section the five focus areas in which the IDs or CLDs are identified and described. These are:

- ELV Supply
- Parts and Scrap Sale
- Premises
- Workforce
- Industry Image

For each area, the emerging dynamic hypothesis and related ID or CLD is presented and described in the following subsections.

5.1.1 ELV Supply, Demand, and Disposal

This subsection first brings into context the factors that auto recyclers consider when sourcing ELVs before highlighting the dynamics of ELV sourcing at salvage car auctions.

As deduced from interview data, to determine the suitability of ELVs for their operations, auto recyclers several assess vehicle specific factors (cost, location, condition) and business-related factors (available cash, yard space).

Regarding the sourcing of ELVs, auto recyclers rely primarily on salvaged car auctions to locate stock for their operations. They also rely on other sources, such as the public and crash repairers, depending on their business model (e.g. You-Pull-It). There is also an emerging stream which is direct from insurance companies that bypasses auction houses.

5.1.1.1 Factors considered for sourcing of ELVs

When prompted for the factors that auto recyclers take into consideration when deciding on acquiring ELVs (Figure 5.1 on page 102), the following ELV specific factors were identified:

• ELV Cost of Transport: as most ELVs are either unregistered or unroadworthy, there is a significant towing cost involved to bring them to the premises. This cost, which is dependent upon the ELV Location Distance, varies widely from as little as 50 dollars per vehicle (Interview 5) to several hundred Dollars if the ELV is interstate. Automotive recyclers view this cost as a factor that negatively impacts their Business Profits, Cash Reserves, and subsequently, the number of ELVs bought.

• ELV Cost of Purchase: it is perhaps the most crucial factor in the process of sourcing ELVs. In most cases, Automotive recyclers decide on whether an ELV is worth buying or not based on this factor along with the inherent ELV Value as Parts and as Scrap. Like the ELV Cost of Transport, this factor also impacts on the Business Profits as it ties significant amounts of their Cash Reserves. This factor varies in value from as little as 0 Dollars (as vehicle removal service) to several thousands of Dollars (at salvaged car auctions).

• ELV Damage: the extent to which an ELV is damaged determines its value as parts. For most auto recyclers this value is highly tied to the condition of mechanical components. This value is also seen differently by different auto recyclers. Those that operate in a niche market (e.g. specialising in specific brands/models) may see more value in an ELV than You-Pull-It type recyclers. This disparity in the perceived value may be due to the existing trade links with customers operating around that niche.

• ELV Age: like ELV Damage, this factor impacts the ELV Value as Parts. It also influences the perceived ELV Value as Scrap. An older ELV may be seen by the You-Pull-It type recyclers that rely on low profits high volume to derive their profits, as their baseline revenue stream. In the worst-case scenario, if the ELV provides little or no revenue for parts, it would still be sold as scrap metal to metal recyclers. Note that this value as scrap is contingent upon the scrap metal price which fluctuates according to the global scrap metal price.

Most participants noted that the price that metal recyclers are willing to pay for scrap depends on two factors: the first one is the currency exchange rates that affect the willingness of metal recyclers to purchase more scrap feedstock as it has a significant effect on their revenue. The second one is the nearing deadline for an export shipment of scrap metal, as the metal recyclers revenue
is chiefly created when scrap metal is taken onto the vessel. While this area of interest may lie outside the scope of this work, the observation made by the auto recyclers about the metal recyclers provides another insight into the business of recycling. Regardless of the product being recycled, the willingness of businesses to acquire more feedstock for their operations highly depends on the business ability to meet demand and create revenue for the business.

Figure 5.1: An Influence Diagram of Factors Considered when Sourcing ELVs

Put differently, if demand for a particular product suddenly stops then businesses are less likely to go after more feedstock as the potential to create more revenue is suddenly abolished. This generalisation does not negate the possibility of finding other markets for the same product. Auto recyclers can be seen operating under this very paradigm (Figure 5.2 on page 103). One interviewed recycler saw more potential in the market demand for used parts and adapted their business model accordingly.
5.1.1.2 Sources of ELVs

When discussing the sources of ELVs with automotive recyclers (Figure 5.3 on page 104), it was established that the essential three sources volume-wise are: the public, salvaged car auctions and crash repairers. A limited importation activity from Japan is identified and explained and the end of this subsection.

With the public and crash repairers wanting to dispose of old vehicles, the cost of ELV purchase in these situations is usually low to almost zero dollars (as pointed out in the previous section). ELVs sourced from the public and repairers tend to be older models/makes with mechanical failures that negatively impact the value of ELV as parts. Quality ELVs with highly valuable parts, however, are sourced primarily from salvage car auctions. While some large-scale auto recyclers rely heavily on sourcing from the public with little cost, some specialised auto recyclers source almost 100% of ELVs from these auctions where the cost of purchase amounts to several thousands of dollars.

Based on the above, it becomes clear that the sourcing of ELVs from auctions is an essential activity for auto recyclers from a business standpoint. Despite being the costly option, sourcing stock from salvage auctions is essential as it provides them with a quality feedstock that can be dismantled and sold as quality parts.

However, where do these ELVs come to auctions in the first place? As established from the auction houses interviews, 99% of their stock comes from auto insurance companies. Insurers write off a damaged vehicle when it is deemed
unaecnornnl for them to repair it as they pay outh the policyholder.

Figure 5.3: An Influence Diagram of the Sourcing of ELVs

The business model that auction houses follow means that their turnover is highly coupled with the number of cars they turnover and the hammer price on the cars. This model means that their suppliers (insurers) would benefit from a higher return on the salvaged stock, consequently making them the preferred option for disposing of damaged vehicles. It also means that to push the final bidding price on vehicles, many bidders need to be present during auctions.

These bidders can be any person that presents a valid form of ID and pays a bidder registration fee. These non-trade bidders are considered as backyarders by auto recyclers. They attempt to source damaged vehicles from auctions, for parts and to possibly repair them to sell them on the market as used vehicles. They compete with the trade bidders at the auctions, driving the final price upwards a desired outcome by the auction houses. Recently laws passed in NSW (Written-Off Act) that made it impossible to re-register a written-off vehicle is seen by auto recyclers as a policy devise that can deter these non-trade bidders from entering the auctions in the first place.

This stiff competition at auction houses has led some auto recyclers to by-pass the current arrangement by sourcing their stock directly from auto insurers through strategic alignment. This recent trend, combined with the new laws
5.1. QUALITATIVE SD MODEL

mentioned earlier, is seen to lower the price of salvaged vehicles at auctions as fewer bidders turn up for auctions. The trend will also divert potential salvage stock from being sent to auction houses. The net effect on auction houses might be a negative impact on their turnover as less stock is handled.

It is unclear from the interviews the extent to which this trend (auto recyclers sourcing stock direct from insurers) is prevalent in the industry. Revisiting the collected turnover data, it can be established that approximately 8% of the total ELVs reported by all participants are handled by recyclers having special arrangements with an auto insurance company though sourcing of ELVs from insurers is not exclusive (the recyclers reported they still source some of their stock from salvage auctions).

Importing from other countries is another viable source of ELVs. Several participants have indicated that they have tried to import from overseas, with Japan as the most viable due to the accessibility of quality stock for all brands including European makes. It was established that the Australian Dollar/Japanese Yen (AUD/JPY) exchange rate is the most important motivating factor for this activity. When JPY is relatively cheap, sourcing ELVs from Japan becomes cost effective as it cheapens the ELV cost of purchase. Even after adding the agent fee and shipping costs, sourcing ELVs from Japan is highly competitive with the local sourcing from auctions where the competition highlighted above has been driving up ELV prices.

5.1.2 Parts and Scrap Sale

The last most significant area that emerged from the interview data analysis is the sale of parts and scrap metals (Figure 5.4 on page 106) resulting from the dismantling process.

Automotive recycling in Australia is an economic activity that depends on several streams of revenue (mechanical repairs/vehicle servicing, parts trade, scrap metal trade) and different markets (trade, public).

The revenue intended from the dismantling activity is created through the sale of used parts (both mechanical and replacement) and the sale of the remaining hulks. Revenue from the latter is highly coupled with the scrap metal price which is dictated by the prices on the world markets. As for the revenue from used parts, it is driven by the demand for used parts which also motivates recyclers to seek ELVs to meet that demand.

As more ELVs are acquired, the holding yard capacity is reached which con-
strains further ELV purchases. When metal recyclers offer high enough prices for hulks, ELVs are disposed of even when they might still have good parts on them. This response frees up the space available for sourcing more ELVs.

For auto recyclers that dismantle the ELVs in full, a similar dynamic loop exists: as more parts are dismantled off ELVs, the available shelf space is reduced forcing the recyclers to hold off dismantling. They even try to sell off parts, sometimes by attempting to market them at lower than market value to free up shelf space (not shown on diagram).

It is interesting to note through this observation that the average auto dismantling business consequently relies on the demand for used parts and the scrap metal prices that are both fluctuating and are difficult to forecast. This uncertainty may explain why recyclers explore more stable streams of revenue (such as servicing, mechanical repairs) to supplement their fluctuating revenue. It could also explain the recent trend in adopting industry-connected ICT solutions that allow them pooled access to used parts inventory which increases their chances of achieving a sale on parts (earning a commission in the process) from other recyclers.

Figure 5.4: An Influence Diagram of Revenue Derived from Used Parts/Scrap
5.1.3 Premises

One of the central business characteristics questions focused on premises area size (Figure 5.5 on page 108) as operating an automotive recycling business is space demanding. Interview data indicate that auto recyclers who can adapt their premises to changes are more likely to stay longer in business.

The interviewed automotive recyclers indicated that as their turnover and profits grow over time so does the need to expand their business premises. This growth, through renting an extra block of land next door or opening a branch across town significantly affects their profits. This effect leads them to think of new business processes or ways to optimise their operations so they that maximise on their investment costs. In some cases, the net effect becomes to downsize the premises while optimising the operations and in turn achieve a higher turnover.

This simple feedback structure highlights a critical dimension in the business of automotive recycling which for long has been associated with the need for a large block of land.

The rising costs of premises through increases in property taxes or rental was initially being considered as a limiting growth factor before conducting the interviews. However, participants have indicated that while premises costs remain significant and are always on the rise, they have adopted changes in their business structure through business optimisations to cope with the increasing costs.

Operations optimisation which will appear in the following sections is used as an umbrella term to describe changes made in one or more of the following business areas to minimise costs or maximise revenue:

- Premises: expand, shrink, or relocate.
- Workforce: grow, reduce, or retrain.
- Practice: restructure business (add or remove products or services), invest in ICT or marketing.

5.1.4 Workforce

Automotive recycling is a labour-intensive operation. Operators that can adapt their workforce (size, cost, skill level) to changes are more likely to stay longer in business. (Figure 5.6 on page 109)
As Business Turnover increases, automotive recyclers increase their Workforce Size to keep up with the increased workload. Labour Cost is one of the primary costing factors that affect auto recyclers’ profitability.

As costs grow, auto recyclers tend to look for ways to optimise their business operations. They do so by adjusting their Workforce Skill Level to maximise the efficiency of their workforce. The response includes hiring new skilled workers, retraining current workers, or dismissing unskilled workers. As a result, their Workforce Size dynamically changes.

Apart from a recycler operating for less than two years, all participants indicated that their workforce size is continually changing.

5.1.5 Industry Image

When asked about memberships with industry associations (Figure 5.7 on page 109), most participants (seven out of eight) indicated they are members of at least an industry body. Automotive recyclers place great emphasis on the environment aware practice they follow which they believe is helping better the industry reputation among the public.

Furthermore, industry associations try to promote an environmentally friendly practice as the proper thing to do for the environment and the industry. This motivating factor has been used to encourage non-members to join the body.

Automotive recyclers associate non-members with an illegal practice damaging
5.1. QUALITATIVE SD MODEL

Figure 5.6: A Causal Loop Diagram of the Workforce

to the environment. They view the lack of policy and policing as the primary cause for this practice which has been tarnishing the industry reputation that they have been trying to improve.

It was noted from the interviews that there might be a cyclic relationship between business survival and the industry reputation. This observation is based on the pride of auto recyclers staying in business for almost 30 years which they view as an indicator of trust among their suppliers, customers and the public.

Figure 5.7: A Causal Loop Diagram of Industry Image
5.1.6 A Note on Industry Challenges

Using interview data, this subsection presents a summary of challenges facing the automotive recyclers. These challenges are categorised by scope (business, industry, policy/law) and grouped by impact area. Where a challenge impacts a broader or non-specific area, it is placed under a general business group.

- Business level (Table 5.1 on page 110),
- Industry level (Table 5.2 on page 111),
- Policy/law level (Table 5.3 on page 111).

Building on these challenges, a short list of possible scenarios is deduced (Table 5.4 on page 112).

<table>
<thead>
<tr>
<th>Impacted Area</th>
<th>Challenge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Premises</td>
<td>Land rental/tax costs</td>
</tr>
<tr>
<td></td>
<td>Upgrade of facilities</td>
</tr>
<tr>
<td></td>
<td>Business location</td>
</tr>
<tr>
<td>Workforce</td>
<td>Labour costs</td>
</tr>
<tr>
<td>ELV Sourcing</td>
<td>Increasing ELV purchase costs</td>
</tr>
<tr>
<td></td>
<td>Competition from unlicensed traders</td>
</tr>
<tr>
<td></td>
<td>Competition from other recyclers</td>
</tr>
<tr>
<td></td>
<td>Lack of stock to meet demand</td>
</tr>
<tr>
<td>Parts and Scrap Sale</td>
<td>Revenue Growth</td>
</tr>
<tr>
<td></td>
<td>Scrap steel prices low (low revenue from scrap)</td>
</tr>
<tr>
<td>General Business</td>
<td>Viability of auto recycling as a business</td>
</tr>
<tr>
<td></td>
<td>Business growth/expansion</td>
</tr>
<tr>
<td></td>
<td>Reducing costs</td>
</tr>
<tr>
<td></td>
<td>Become more efficient (more revenue, less costs)</td>
</tr>
</tbody>
</table>

Table 5.1: Business Challenges Categorised by Impact Area

5.1.7 Aggregated Views

This section presents aggregate views of the model areas presented thus far. When viewing the factors influencing the business of automotive recycling, at least two chief perspectives may be assumed.
5.1. QUALITATIVE SD MODEL

<table>
<thead>
<tr>
<th>Impacted Area</th>
<th>Challenge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry Connections</td>
<td>Industry shrinking</td>
</tr>
<tr>
<td></td>
<td>Environmental awareness</td>
</tr>
<tr>
<td></td>
<td>Industry image</td>
</tr>
<tr>
<td></td>
<td>Alliance with other dismantlers</td>
</tr>
<tr>
<td>Parts and Scrap Sale</td>
<td>Acceptance by auto-repair industry to re-use parts</td>
</tr>
<tr>
<td></td>
<td>Marketing used parts as viable alternative to new parts</td>
</tr>
</tbody>
</table>

Table 5.2: Industry Challenges Categorised by Impact Area

<table>
<thead>
<tr>
<th>Impacted Area</th>
<th>Challenge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workforce</td>
<td>Work laws</td>
</tr>
<tr>
<td>ELV Sourcing</td>
<td>Lack of policy in the trade of ELVs</td>
</tr>
<tr>
<td></td>
<td>Economic write-off</td>
</tr>
<tr>
<td></td>
<td>Different vehicle legislations across states</td>
</tr>
<tr>
<td>General Business</td>
<td>Licensing requirements/costs</td>
</tr>
</tbody>
</table>

Table 5.3: Policy or Law Challenges Categorised by Impact Area

- The first is an external view that focuses on the interactions with the suppliers/customers of ELVs/parts (Figure 5.8 on page 113).
- The second is a view from the inside which focuses on the operational aspects of ELV recycling (Figure 5.9 on page 126).

The two complementing aggregate views suggest that while there are factors that are beyond the control of the operators, the industry operators may have leverage over certain internal factors to improve their financial performance and the industry image. Both views warrant further exploration which requires more research, further data sourcing and collection, and engagement with various groups of stakeholders depending on the view.

5.1.8 Observations

The qualitative model represents an attempt at capturing and structuring the complexity that emerged from the interview data and industry reports.

The first observation that may be drawn from these conceptual models is that ELV recycling is a complex issue where multiple factors -external and internal to the industry, influence the behaviour of the industry.
Focus Area | Scenarios
--- | ---
Premises | Increasing land rental costs, having to upgrade facilities/relocate to adapt to market changes
Workforce | Tightening of work laws (dismissal, compensation) and increasing labour costs (Labour price index)
Industry Connections | Promoting environment friendly practice, clustering of recyclers, with less recyclers
ELV Sourcing | Increasing ELV purchase costs coupled with strong competition, reduction in available and suitable ELV stock, economic write-off implemented, strong policing on illegal ELV trade, harmonisation of laws across states
Parts and Scrap Sale | Stagnant price of scrap steel, public and insurance / auto-repair industries shift to used parts where possible,

Table 5.4: Preliminary Scenarios by Focus Area Identified from Challenges

Externally, the industry is influenced by an interplay of the insurance industry practice in writing off vehicle damage claims which largely influences whether a vehicle becomes an ELV -a donor for parts, or a repairable write off -potential source of demand for parts, in addition to a fluctuating demand for used parts driven by the motorists and the public.

The industry also faces internal challenges, namely operational, spanning the sourcing of ELVs in the face of a growing and unfair competition from the back-yarders, the storage of ELVs and dismantled parts under space constraints, and managing the facilities and workforce to maintain or improve profitability.

It may be worthwhile further exploring the internal perspective because the industry possesses leverage on these operational elements. The assumed study path is through developing the conceptual SD model into a simulation model that captures and analyses key variables and influences in the five main areas of interest. The model is presented in the next section.
5.2 Simulation SD Model

Published Work\(^\dagger\)

The SD model five sectors along with the underlying connecting financial sector are presented in this section. Model formulas and variables initial values are tabulated and explained in Appendix H. Each sector of the model is assigned a heading under which:

- the sector purpose is presented,
- the flows and variables are described and plotted against real data where possible,

\(^\dagger\)The conceptual high-level models presented in this section were published in El Halabi, E., Doolan, M. and Featherston, C. (2013) System Dynamics and Scenario Planning: Implementation Challenges Systems Engineering and Test and Evaluation Conference, SAPRO
key variables normalised by the number of legitimate automotive recyclers, or other variables are plotted as the normalisation sometimes generates slightly different observations, and

- important observations on variables behaviour are noted.

It is important to note that this model results from several iterations. Stocks and variables deemed unnecessary or non-critical were excluded. Some variables/stocks/flows that were part of a modelling area or sector in the qualitative model were moved to other sectors to maintain uniformity and increase clarity. For the same reason, some variables were renamed and hence will appear slightly different from the qualitative model.

It is also worthwhile mentioning that the model represents an aggregated perspective on the automotive recycling industry. A perspective which necessitates assumptions on a myriad of variables for which data is either non-existent or difficult to acquire. Key modelling assumptions are addressed in Section 6.2.1 before presenting the SD model sectors.

### 5.2.1 Modelling Assumptions

Modelling, in general, takes a reductionist albeit practical approach. SD modelling is no different to this attribute, and so is this application of SD. However, within the model boundary, there exists another dimension of reductionism that underlines the variables and their values. This necessity, yet again pragmatic, is a result of data scarcity and difficult-to-measure metrics. In keeping with the overarching principle of transparency, it is essential to document the assumptions. Table 5.5 on page 127 summarises the assumptions for data values organised by model sector and variables. General model assumptions are:

- Inflation and currency exchange rate fluctuations are ignored.

- Scrap prices, workforce wages, demand for parts, new car sales are exogenous and unaffected by the industry financial performance.

- Market entrants rely on general information about the industry to decide whether to invest in a new auto recycling business. The main factors considered are existing competition from legitimate auto recyclers (number of established operators), the prevalence of backyarding (Number of backyarders), potential return rate (Profit over revenue) and the regulations or licensing requirements.
5.2. SIMULATION SD MODEL

5.2.2 ELV Supply, Demand, and Disposal Sector

This sector (Figure 5.10 on page 128) encompasses the flow of cars/ELVs from new to scrapping while focusing on the factors driving up demand for ELVs and the ELV market price.

5.2.2.1 Purpose and Description

The purpose of the ELV Supply, Demand, and Disposal sector is to determine the ELV purchase costs as well as the revenue from the sale of ELV bodies/non-dismantled parts as scrap. The sector uses fleet growth data, the total number of automotive recyclers including backyarders, and other intermediately calculated variables (competition for ELVs, ELV market price, scrap metal price).

In this sector, the vehicle attrition rate is correlated with new car sales at around 62% of the latter. The simulated fleet growth tracks well with available data as shown in Figure 5.11 on page 129. Similarly, the simulated attrition rate tracks well with available data as shown in Figure 5.12 on page 129.

It is assumed that the metal recycling industry directly acquires 20% of the ELVs on the market. The ELV exports from Australia are considered insignificant (less than 10%) and hence are ignored. The automotive recyclers acquire the remaining 80% ELV stock on the market. Each year it is assumed that all ELVs in the yards are disposed of for scrap. The plotting of the ELVs on Market, ELVs Acquired, and ELVs in Yard, and the Dispose variables is not necessary as the plot of attritioned vehicles represents them all; the first three multiplied by a factor of 0.8, the latter at a factor of 0.8 delayed by a year.

In order to determine the market price for ELVs, a Demand Pressure stock is modelled using a Demand Differential variable which is driven by the number of ELVs on the market, and number of competitors - the total number of automotive recyclers including backyarders. The resulting behaviour for the Competition for ELVs and ELV Demand Pressure is shown in Figure 5.13 on page 130.

The ELV Purchase Costs (Figure 5.14 on page 130) are derived using the ELV Market Price, and ELVs Acquired variables.

On the revenue side, the revenue from the sale of disposed ELVs is derived from the price of scrap metal which uses the reported scrap ferrous index (ABS 2012) for the available years before growing at 3.5% annually. The Scrapped ELV Weight is set at 1.233t (Environment Australia 2002) then reduced by about 10% around 2008 (dismantling trial in 4.4.1). The Scrap Metal Price and Revenue variables are plotted in Figure 5.15 on page 131.
5.2.2.2 Key Variables Normalised

The ELVs in Yard (Figure 5.16 on page 131), ELV Purchase Costs (Figure 5.17 on page 132) and Scrap Metal Revenue (Figure 5.18 on page 132) variables normalised by the number of legitimate recyclers are presented in their respective figures.

5.2.2.3 Observations

The simulated automotive fleet stock behaviour seen in Figure 5.11 on page 129, growing by 2.60% per year on average over the model horizon, tracks well with the reported data for 2003-2012 (2.63% versus 2.53% annual increase). Furthermore, the trend of the vehicles attritioned shown in Figure 5.12 on page 129 tracks well and mimics the oscillations for the periods 2004 to 2008 and 2011 to 2012. It is, therefore, safe to establish that linking the attrition rate the new car sales rate is a valid -even though simplified, approach to estimate fleet growth and vehicle retirement rates.

The competition for ELVs and the demand pressure for ELV plotted in Figure 5.13 on page 130 follow an upward trend with 19.43% and 3.10% average annual increase respectively over the model horizon. This behaviour comes as expected because the Increase/Decrease and Demand Differential variables were formulated to reflect an ever-increasing demand.

The resulting ELV market price and purchase costs, shown in Figure 5.14 on page 130, exhibit average annual increases of 0.95% and 3.65% respectively. When normalised by the number of enterprises, the ELV purchase costs per enterprise plotted in Figure 5.17 on page 132 increase by 4.24% annually on average which represents a 16.16% jump over the overall industry figure.

On the revenue side, the scrap metal price and revenue from scrap metal shown in Figure 5.15 on page 131 increase by 7.32% and 9.74% annually on average respectively. The revenue from scrap metal per enterprise plotted in Figure 5.18 on page 132 exhibits a 10.41% annual increase on average.

The ELVs on Market, ELVs Acquired, and ELVs in Yard, and the Dispose variables represented by the Vehicles Attritioned variable in Figure 5.12 on page 129 exhibit an annual increase of just under 2.97% on average (as mentioned earlier, merely multiplied by 0.8). By contrast, the ELVs in Yard per Enterprise shown in Figure 5.16 on page 131, increases by 3.57% which is 20.2% higher than the overall industry figure.
5.2.3 Used Parts Dismantling Sector

This sector (Figure 5.19 on page 133) focuses on the flow of the parts dismantling and selling activities and the factors influencing them.

5.2.3.1 Purpose and Description

The purpose of the Used Parts Dismantling sector is to determine the revenue from the sale of dismantled parts by using the demand for used parts, limitations imposed by space constraints and an average price per part.

The dismantling of parts from ELVs is based on an estimate of 27 parts per ELV based on data provided by a large volume automotive recycler and provided there is ample storage space. Dismantling slows down to 24 when the parts storage density (Figure 5.20 on page 133) threshold of 2.5 parts per sqm is exceeded.

The selling of parts is assumed to constitute 90 per cent of the stock of parts (as dismantlers usually only take off parts that are in high demand) increasing or decreasing depending on the demand growth for used parts or through a randomised function that uses the mean and standard deviation for that same demand growth data. The average price per part is assumed 87.3 dollars (dismantling trial in 4.4.1).

The resulting stock of Dismantled Parts and the revenue from parts selling are plotted in Figure 5.22 on page 134 and 5.21 on page 134 respectively.

5.2.3.2 Key Variables Normalised

The revenue from the used parts sales per enterprise is plotted in Figure 5.23 on page 135.

5.2.3.3 Observations

The parts storage density variable (5.20) exhibits a downward trend away from the threshold. Moreover, as the parts selling rate is formulated to be lower than the available stock, the stock of Dismantled Parts (Figure 5.21 on page 134) continues to grow at about 3.2% per year approximately, reflecting the current norm in the industry of parts stockpiling.

The revenue from parts sales for the industry (5.22) grows 3.54% per year, whereas if normalised by the number of enterprises (5.23) the growth is 16.38% higher, or 4.12% per annum.
5.2.4 Premises Sector

This sector (Figure 5.24 on page 135) treats the premises area size as a stock that can be expanded/shrunk depending on the financial performance of the industry.

5.2.4.1 Purpose and Description

The purpose of the Premises sector is to determine the total area size (Figure 5.25 on page 136) and the resulting costs borne by the industry (Figure 5.27 on page 137) by using a growth function determined through a profit revenue ratio variable (calculated in the financial sector) and a shrinkage function tied to the cost efficiency of the premises (Figure 5.26 on page 136). The assumed cost per sqm is 11.22 dollars a year. Shrinkage remains nil as the threshold of 0.5 (profit over premises costs) is never reached.

5.2.4.2 Key Variables Normalised

The Premises Area Size stock -coincidentally already normalised, which also reflects the Premises Costs per Enterprise (by a factor of 1 to 11.22) is presented in Figure 5.28 on page 137.

5.2.4.3 Observations

The simulated combined premises area size of the automotive recyclers and associated costs plotted in Figure 5.25 on page 136 and Figure 5.27 on page 137 respectively, grow by about 3.34% per year on average. The behaviour tracks well with the area size data (3.39% versus 3.42% annual increase for 2003-2012).

The area size per enterprise and associated costs (Figure 5.5 on page 108) grow at 4.28% which represents a 26.53% increase compared to the overall industry figures. The higher growth rate reflects the increase in the capacity of recyclers to hold more ELV stock in the yard, supporting the observation made in the ELV Supply, Demand and Disposal Sector.

5.2.5 Workforce Sector

This sector treats the workforce as a stock that can be grown and shrunk depending on the financial performance of the industry.
5.2.5.1 Purpose and Description

The purpose of the Workforce sector (Figure 5.29 on page 138) is to determine the size of the workforce employed by the industry (Figure 5.30 on page 138) and the resulting employment costs (Figure 5.31 on page 139) by using a hiring function determined through the profit revenue ratio (calculated in the financial sector) and a dismissal function tied to the cost efficiency of the workforce. The calculation for the costs first relies on the reported wages (IBISWorld, 2011) for available years before reverting to compounded growth of 1% annually.

5.2.5.2 Key Variables Normalised

The workforce size per enterprise and the workforce costs per enterprise are plotted in Figure 5.33 on page 140 and 5.34 against the available data.

5.2.5.3 Observations

The behaviour of the simulated workforce stock (Figure 5.30 on page 138) follows an inversely proportional trend that tracks well with the real data’s — the simulated stock drops by 1.92% per year on average versus 1.95% over the 2003 to 2012 period. Over the model horizon, the stock decreases by 0.87% per year on average.

The workforce costs (Figure 5.31 on page 139) variable initially follows a rapidly decreasing trend similar to the workforce costs then rebounds in 2012, closely following the reported data. The rate of decline over the 2003-2012 period is 3.56% versus 3.54% for the available data. Overall, the decline averages 0.8% per year.

Despite the drop in the overall industry employment figures, the normalised number of employees per enterprise (Figure 5.33 on page 140) exhibits a rebound behaviour after the initial drop. Over the period 2003-212, the declining trend -averaging 1.18% per year, resembles that of the real data at 1.02%. The overall decline across the model horizon averages an almost flat 0.28% per year decrease which represents a 72.5% drop compared to the overall industry figure. This discrepancy could be attributed to the hiring of employees from folded enterprises to grow operations or cope with increased workload.

The workforce costs per enterprise (5.34) tracks well with the available data, declining by 2.19% on average between 2003 and 2012 (compared with 2.24% for reported data). Over the model horizon, the variable rebounds and averages a
0.25% decline per year.

5.2.6 Industry Image Sector

This sector (Figure 5.35 on page 141) focuses on the flows of recycling enterprises and their competition, the backyards, from creation to folding and an interplay of factors driving these flows.

5.2.6.1 Purpose and Description

The purpose of the Industry Image sector is to determine the number of automotive recyclers in operation including the backyards.

Industry Reputation is assumed a primary driving factor as it influences the rates at which new players enter the industry, whether as new establishments or as backyards wanting to legitimise their operations. Industry Reputation is proportional to the number of enterprise and profit revenue ratios, and inversely proportional to environmental impact and the number of backyarders.

Conversely, the Environmental Impact variable is proportional to the number of backyarders and inversely proportional to the number of enterprises and licensing/enforcement which is set to 1 in this baseline scenario. These relations are based on an unrealistic assumption that legitimate enterprises follow the local environmental protection guidelines whereas the backyards do not.

Backyards currently have no incentive to convert to legitimate operations under the conditions of the baseline model. The legitimisation ratio (which is used as an inverse proportion) is set to a high value (1250) to have a nil flow between the stocks of Backyarders and Enterprises.

Figure 5.36 on page 141 shows the number of enterprises versus available data, the number of backyarders and the total. Figures 5.38 on page 142 and 5.39 on page 143 present the behaviour of creation/folding rates for the enterprises and backyarders respectively. While Figure 5.37 on page 142 shows the behaviour of Industry Reputation along with its trendline and the behaviour of the Environmental Impact variable which also corresponds to the Enterprises/Backyarders ratio.

5.2.6.2 Key Variables Normalised

The Environmental Impact per Enterprise is plotted in Figure 5.40 on page 143.
5.2. SIMULATION SD MODEL

5.2.6.3 Observations

The number of enterprises (Figure 5.36 on page 141) declines by 0.57% per year on average over the model horizon. Over the 2003-2012 period, it declines by 0.85% closely following the real data’s decline of 0.87% per year. Conversely, the number of backyarders increases by 3.65% per year.

The rates of enterprises and backyarders creation exhibit different behaviours (Figure 5.38 on page 142 and Figure 5.39 on page 143) with the former slightly increasing to and hovering around three new enterprises and the latter steadily increasing to reach ten backyarders per year. The rates of folding or closure of enterprises and backyarders respectively also exhibit different behaviours stabilising around five folded enterprises versus three backyarders. These expected behaviours are based on the assumptions that the backyarders have little deterrents and overheads to establish operations and are created at a higher rate than legitimate enterprises.

The combined total number of recyclers exhibits a decline initially following the behaviour of the enterprises stock then rebounds as the number of backyarders becomes more significant. This behaviour results in an almost flat 0.5% annual increase by 2023.

The reputation of the industry exhibits an oscillating but increasing behaviour which averages an increase of 20.70% per year - as industry image is formulated to be strongly tied to its profitability.

The environmental impact for the industry and per enterprise both follow a slow but steady annual increase at 4.25% and 4.85% respectively. The higher rate of the latter of 14.12% over the former can be attributed to the decrease in the number of enterprises in comparison with the increasing number of backyarders.

5.2.7 Financial Sector

The five model sectors presented thus far are linked through the following variables: Profit, Profit Revenue Ratio, Premises Costs Revenue Ratio, Enterprises, and Total Number of Auto Recyclers. In contrast to the other five sectors modelled after the interview data, this sector (Figure 5.41 on page 144) groups the variables determining the cash flow or financial performance of the industry. It may be treated as a common denominator sector for other model sectors.
5.2.7.1 Purpose and Description

The purpose of this sector is to calculate the revenue (Figure 5.42 on page 144) and the profit (Figure 5.43 on page 145) of the industry based on the revenue and expenditure factors deduced in the other sectors (Parts Revenue, Scrap Metal Revenue, ELV Purchase Costs, Workforce Costs, and Premises Costs).

5.2.7.2 Key Variables Normalised

The value of the Profit Revenue Ratio (Figure 5.44 on page 145) at each period corresponds to the profit made the previous year to reflect the current practice in the industry: decisions about hiring, premises expansion and purchasing more ELV stock are based on the profit made in the most recent accounting period.

The revenue and profit per enterprise are plotted in Figure 5.45 on page 146 and Figure 5.46 on page 146 respectively. The revenue and profit per ELV are also plotted in 5.47 and 5.48 respectively.

As all the costs and revenue variables have already been presented, it is worthwhile to showcase a similar plot (Figure 5.49 on page 148) highlighting the ratio of Scrap Metal to Parts Revenue, and the ratio of ELV Purchase Costs to Premises and Workforce Costs.

5.2.7.3 Observations

The industry revenue (Figure 5.42 on page 144) follows an upward oscillating trend increasing by 3.85% a year on average. This trend represents an amplified and significantly different response compared with the reported data for 2003-2012 (2.51% versus 1.47% average annual increase respectively).

The industry profit (Figure 5.43 on page 145) exhibits an oscillating behaviour averaging an annual increase of 20.08%, whereas for 2003-2012 and compared with reported data, the increases are 22.83% and 5.71% respectively.

The profit to revenue ratio or profit margin also exhibits a vastly different behaviour to the available data. The former oscillates averaging 16.29% over the 2004-2012 period versus a stable 9.53% for the latter. Overall, the variable averages 18.50%.

The behaviour of revenue per enterprise (Figure 5.45 on page 146) is similar to that of the industry, but increases at a by 4.44% on average annually (or 15.32% higher than the industry) over the whole run. For 2003-2012, the trend exhibits an amplified and significantly different response, increasing at 4.09% when compared
5.3. OBSERVATIONS SUMMARY

with the real data 2.26% average annual increase.

Unsurprisingly, the profit per enterprise behaviour (Figure 5.46 on page 146) follows closely the industry’s increasing by 22.25% over the model horizon. This trend also represents an amplified response compared with the real data for 2003-2012 (32.99% versus 6.24% average annual increase respectively).

The revenue per disposed ELV (Figure 5.47 on page 147) shows that the model tracks well - markedly well for 2003-2009, although 8% higher on average than the available data. Meanwhile, the profit per disposed ELV (Figure 5.48 on page 147) exhibits a somewhat unrelated response to the available data which hovers around $199 in profit per ELV (median value).

The revenue and profit variables, therefore, both appear significantly different from the reported data, which suggests that either their values have been over-estimated in the model or that the accuracy of the reference or reported data is questionable.

The ratio of revenue from parts sales over scrap metal sales (Figure 5.49 on page 148) exhibits an inversely proportional behaviour dropping from around 25 to 8, or about 4.55% decrease per year on average. This change suggests that, if the scrap metal prices continue to increase, the revenue from scrap metal sales will become a promising and significant -perhaps under-explored, component of revenue for automotive recyclers.

By contrast, the ratio of purchase costs of ELVs over the premises and workforce costs increases from 1.85 to 3.45, or about 3.34% per year on average. This change suggests that if competition for ELVs continues to increase, the costs to acquire ELVs will almost double relative to the operational costs.

5.3 Observations Summary

This section provides a summary of the observations made about the qualitative and simulation SD models. These observations about the model sectors, including behaviours and dependencies, shall be explored further in Section 7.1.

5.3.1 Qualitative SD Model

Automotive recycling is a complex issue where external and internal factors influence the behaviour and financial performance of the industry:

- Externally, the supply and demand of both the ELVs and dismantled parts
is determined by the behaviour of the automotive insurers and the public/motorists for writing off, repairing, or retiring the ELVs.

- Internally, the industry deals with operational challenges covering decisions on ELV sourcing, dismantling and disposal, and the management of facilities and workforce while aiming to maintain or increase profitability.

Given the data scarcity, cost constraints, and the immediate leverage the industry has on internal factors, it may be more worthwhile to focus the modelling effort on the internal view analysing the identified five main areas of interest along with the financial performance: ELV supply/demand and disposal, workforce, premises, parts sales, and industry image.

5.3.2 Simulation SD Model

The baseline model, which has been developed based on the internal view of the industry challenges, tracks well with the sourced data for the first period while capturing the trends for each of the variables in the main five model areas.

Of notable mention are the Revenue and Profit variables that exhibit an amplified and significantly different responses from reference data suggesting either that they are either overestimated in the model or that the reference data accuracy is questionable. It is not unreasonable to think that the industry profit may have been deducted from an estimate (probably $200 per ELV) rather than actual profit data.

The slight differences between the fleet growth/attritioned ELVs and the ABS data can be attributed to the modelling assumption that the attrition rate is linked continuously to new car sales.

Keeping in mind that the underlying assumption that the pool of ELVs is exogenous to the industry - that is not influenced by the number of enterprises. The observed growths of the number of ELVs handled, ELV purchase costs, and the scrap metal and parts revenues, workforce size, and premises area size, all normalised by the number of enterprises, correlate with the expectation that the enterprises remaining in operation will take over the market share and resources of folded enterprises. The market share refers to the stock of ELVs, the sale of parts/scrap metal, while resources refer to the workforce and the premises.

The ratio of parts sales to scrap metal revenue exhibits an inversely proportional trend whereby the latter almost triples in comparison with the former
which suggests that there might be a somewhat dormant scope to increase overall revenue.

Over the model horizon, the ELV market price increased by about 20% while the number of backyarders more than doubled, and the number of enterprises dropped by about 10%. The role or effect of the backyarders in driving up the ELV market price may appear mute. However, it is worth noting that the variables represent averages and that a small number of backyarders bidding at a salvage car auction may result in the final price born by legitimate operates to be significantly higher than otherwise.

The SD model, along with its methodological foundation and simulation results, could be safely assumed as a reliable platform to explore various modelling scenarios further.

Conclusions

This chapter presented the qualitative and simulation versions of the baseline SD model resulting from the model conceptualisation and model building stages applied to the automotive recycling industry in Australia.

The five focus areas (ELV Supply, Demand and Disposal, Parts Dismantling, Premises, Workforce, and Industry Image) that emerged from the interview data analysis were explored and analysed.

An internal perspective to the operational issues facing the industry was assumed, and the resulting simulation SD model -and the five sectors corresponding to the focus areas, was showcased along with the simulation results of critical variables compared with real data where possible.

Observations about the baseline model will be further discussed in Section 7.1.

In the next chapter, the baseline model is subjected to the scenarios identified in the SP workshop. Updates to the qualitative model are highlighted, and the simulation results of critical variables are compared.
FIGURE 5.9: AN AGGREGATE CAUSAL LOOP DIAGRAM OF INTERNAL INFLUENCES
### 5.3. OBSERVATIONS SUMMARY

<table>
<thead>
<tr>
<th>Sector</th>
<th>Rationale</th>
<th>Assumptions</th>
</tr>
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</table>
| ELV Supply/Demand/Disposal | Estimate: 1. ELV supply based on actual attrition rate and fleet growth. 2. Competition for ELVs based on ELV supply and competitors. 3. Demand for ELVs and effect on purchase cost of ELVs. Revenue potential from ELVs as scrap. | - ELV price is highly influenced by ELV demand  
- ELV stock is disposed of annually.  
- 80% of ELVs on the market are acquired by the industry, irrespective of their Profit status.  
- Scrap metal price is aggregated from an auto recycler's data at 213AUD per tonne and adjusted according to the scrap metals index from ABS 2012. From 2013 it is estimated to increase at a 3.5% rate year on year which is a conservative estimate given that between 2003 and 2012 the increase was 11% per year on average. |
| Workforce       | Estimate industry workforce costs based on workforce size and average wage. | Average wage uses data from IBIS report and is assumed exogenous. |
| Premises        | Estimate industry premises costs based on area size, cost per sqm, and number of operators. | Cost of land is static at $11.22 per sqm. |
| Parts Sales     | Estimate revenue from parts sales based on actual demand. | - Revenue per part is static at $87.3. Based on a 6-year long sale history of a larger auto recycler.  
- Revenue from other services/products is ignored. |
| Industry Image  | Estimate total number of operators based on the interplay between legitimate operators and backyards influenced by industry reputation, environmental impact and licensing and enforcement. | - Starting ratio of backyards to enterprises is around 12 per cent based on an estimation by an automotive recycler at a salvage car auction (1 in 8-9 bidders not a recognised recycler).  
- Effect of industry reputation on the creation of backyards is ignored, assumed to be minimal. But it influences rate of legitimisation of backyards into established enterprises. |
| Revenue and Profit | Derive revenue and profit of the industry based on the interplay of the other five sectors. | - Revenue and profit are highly coupled with parts sales and ELVs versus scrap metals (90% parts, 10% scrap). This is an aggregate view of the industry based on the data collected from interviews, even though some recyclers may have the ratios evenly split.  
- Total costs are multiplied by 1.25 to account for other overheads not captured by the model and to bring the profit closer to the initial values in the reported data.  
- Profit, as the key variable driving workforce and premises behaviour, is delayed by 1 period. |

Table 5.5: Simulation Model Assumptions
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Figure 5.11: Australian Automotive Fleet versus Available Data

Figure 5.12: Attritioned Vehicles from Australian Fleet versus Available Data
Figure 5.13: Competition for ELVs and ELV Demand Pressure

Figure 5.14: ELV Market Price and ELV Purchase Costs
Figure 5.15: Scrap Metal Price and Scrap Metal Revenue

Figure 5.16: ELVs in Yard per Enterprise
Figure 5.17: ELV Purchase Costs per Enterprise

Figure 5.18: Revenue from Scrap Metal Sales per Enterprise
Figure 5.19: A Stock and Flow Diagram of Parts Dismantling

![Stock and Flow Diagram of Parts Dismantling]

Figure 5.20: Parts Storage Density

![Graph of Parts Storage Density with Threshold]

Threshold: 2.5
Figure 5.21: Dismantled Parts and Used Parts Sold

Figure 5.22: Revenue from Used Parts Sales
Figure 5.23: Revenue from Used Parts Sales per Enterprise

Figure 5.24: A Stock and Flow Diagram of Premises Sector
Figure 5.25: Total Premises Area Size of the Industry versus Available Data

Figure 5.26: Premises Efficiency
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![Graph of Premises Costs](image1.png)

Figure 5.27: Premises Costs

![Graph of Premises Area Size](image2.png)

Figure 5.28: Premises Area Size per Enterprise
Figure 5.29: A Stock and Flow Diagram of Workforce Dynamics

Figure 5.30: Workforce Size versus Available Data
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Figure 5.31: Workforce Costs versus Available Data

Figure 5.32: Workforce Efficiency
Figure 5.33: Workforce Size per Enterprise versus Available Data

Figure 5.34: Workforce Costs per Enterprise versus Available Data
Figure 5.35: A Stock and Flow Diagram of Industry Image Dynamics

Figure 5.36: Enterprises versus Available Data and Estimated Backyarders
Figure 5.37: Industry Reputation, Regression Trend-line and Environmental Impact,

Figure 5.38: New and Folded Enterprises
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Backyarders Created/Folded

![Graph showing Backyarders Created/Folded](image)

Figure 5.39: New and Folded Backyarders

Environmental Impact per Enterprise

![Graph showing Environmental Impact per Enterprise](image)

Figure 5.40: Environmental Impact per Enterprise
Figure 5.41: A Stock and Flow Diagram of the Financial Sector

Figure 5.42: Industry Revenue versus Available Data
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Figure 5.43: Industry Profit versus Available Data

Figure 5.44: Profit to Revenue Ratio versus Available Data
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Figure 5.45: Revenue per Enterprise versus Available Data

Figure 5.46: Profit Per Enterprise versus Available Data
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Revenue per ELV

Profit per ELV

Figure 5.47: Revenue per ELV versus Data

Figure 5.48: Profit per ELV versus Data
Figure 5.49: Ratios of “Parts to Scrap Metal Revenues” and “ELV Purchase Costs to Premises and Workforce Costs”
Chapter 6

Scenarios Applied

In this chapter, the baseline model from the previous chapter is subjected to the four scenarios identified from the SP workshop (Section 6.1). Updates to the qualitative model are highlighted in Section 6.2. Simulation results of critical variables are plotted and compared in Section 6.3.

Section 5.3 summarises the observations drawn from the qualitative and simulation SD models under the four scenarios.

6.1 Scenario Planning Workshop Results

During the SP workshop, several trends and uncertainties facing the automotive recycling industry were identified. The participants helped to arrive at the most critical trend and uncertainty - ELV recyclability and enforced licensing requirements, respectively. When overlaying these dimensions, four distinct scenarios were identified (Figure 6.1 on page 152).

The SP workshop participants explored the impact of each scenario on each sector of the SD model, resulting in Table 6.1 on page 150. These effects, after the conclusion of the workshop, were then systemically interpreted to update the baseline SD model.

Furthermore, the participants also discussed business, industry and government policy responses for each scenario as indicated in Table 6.2 on page 151.

6.2 Qualitative Model

In this section, the interpretation and analysis of the identified effects of each scenario on the model sectors are presented. Each subsection addresses the effects
### Scenario A: Smart Auto Waste SAW
- National licensing increases supply
- Reduced demand for parts
- Compliance
- Mixed skills
- Increased due to necessity to regulate

### Scenario B: How it should be
- Level playing field, Backyarders removed
- Increased demand, Good value
- Larger premises, productivity
- More staff required, Higher waged attracting people to industry
- Image improvement, Environmental leaders

### Scenario C: Wild West
- Auction houses unfettered, Bidding against anybody, eBay trade
- High/low, Fragmented
- No licensing or regulation, Land tax we pay, Backyarder does not, Trade waste agreements
- Business not OHS standards, Open to undesirables
- People think we are Neanderthals, Uncouth

### Scenario D: Big Drama Downward Spiral
- Dramatic reduction in vehicle prices
- Greatly reduced
- Downsize, Sale of Business
- Costs will outweigh sale of materials
- No industry, No reputation, You don’t help people any more

<table>
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<tr>
<th>Scenarios</th>
<th>Model / Focus / Problem Areas</th>
</tr>
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<tbody>
<tr>
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<td>Supply of damaged old vehicles</td>
</tr>
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<td>Scenario A</td>
<td>National licensing increases supply</td>
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<td>Scenario B</td>
<td>Level playing field, Backyarders removed</td>
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<td>Scenario C</td>
<td>Auction houses unfettered, Bidding against anybody, eBay trade</td>
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<td>Scenario D</td>
<td>Dramatic reduction in vehicle prices</td>
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<td>Reduced demand for parts</td>
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<td>Increased demand, Good value</td>
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<td>High/low, Fragmented</td>
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<td>Premises / Land related</td>
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<td>Compliance</td>
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<td>Larger premises, productivity</td>
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<td>No licensing or regulation, Land tax we pay, Backyarder does not, Trade waste agreements</td>
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<td>Labour related</td>
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<td></td>
<td>Mixed skills</td>
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<td>More staff required, Higher waged attracting people to industry</td>
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<tr>
<td>Industry image and reputation</td>
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<td></td>
<td>Increased due to necessity to regulate</td>
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<td></td>
<td>Image improvement, Environmental leaders</td>
</tr>
<tr>
<td>Table 6.1: Scenario Effects on the Five Model Sectors</td>
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</tbody>
</table>
### 6.2. QUALITATIVE MODEL

**Table 6.2: Strategies and Policies in Response to Scenarios**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Business Strategies</th>
<th>Industry Strategies</th>
<th>Policies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario A Smart Auto Waste SAW</td>
<td>Vehicle type specialisation</td>
<td>Industry body stakeholding</td>
<td>EPA Tax, WHS, Consumer compliance</td>
</tr>
<tr>
<td>Scenario B How it should be</td>
<td>Business diversity</td>
<td>Strong advocacy (associations)</td>
<td>Heavy Policing</td>
</tr>
<tr>
<td>Scenario C Wild West</td>
<td>No quality assured, Low cost high density advertising, no offer to honour of warranty</td>
<td>Let’s get some licensing plus enforcement</td>
<td></td>
</tr>
<tr>
<td>Scenario D Big Drama Downward Spiral</td>
<td>Cut costs across the board</td>
<td>Change from part sales to material sales</td>
<td>Government or manufacturer rebates for vehicles dismantled</td>
</tr>
</tbody>
</table>
of a scenario on the model sectors that are given separate headings for better clarity. The narrative forms a linear version of the Scenarios Data Analysis Grid (Appendix I).

6.2.1 Scenario A - Smart Auto Waste

6.2.1.1 ELV Supply Sector

The identified effect "National licensing increases supply" can be interpreted as follows. The reduction of the number of operators, both legitimate and back-yarders will lessen ELV demand, which translates in lower ELV purchase costs. Harmonising the licensing across states and territories also means that competition for ELV stock from interstate buyers will lessen (not at an aggregate level), though this segmentation is not considered in the model scope. Because the changes in values occur in the industry image sector, no additional codes are needed to represent this effect.

6.2.1.2 Demand for Used Parts Sector

The identified effect "Reduced demand for parts" can be interpreted as follows. As the new vehicle ownership is generally more attractive than maintaining an old car, the early retirement of vehicles becomes more common resulting in lower demand for used parts, particularly for vehicles under ten-year-old that currently constitute a significant market for automotive recyclers. The identified code to add to the Demand for Used Parts variable is Demand Downshift for Used Parts
6.2. QUALITATIVE MODEL

6.2.1.3 Premises Sector

The identified effect "Compliance" can be interpreted as follows. Increased costs associated with licensing and enforcement levied by government/industry body. Additional equipment costs are also assumed. The identified code to add to the Premises Costs variable is Compliance Costs (Figure 6.3 on the next page).

6.2.1.4 Workforce Sector

The identified effect "Mixed skills" can be interpreted as follows. Workers require an additional skill set to cope with the shift in the line of business. This will translate into higher labour costs assuming workforce size remains the same. The identified code to add to the Workforce Costs variable is Marginal Training Costs (Figure 6.4 on the following page).

6.2.1.5 Industry Image Sector

The identified effect "Increased due to necessity to regulate" can be interpreted as follows. A regulated industry with minimised competition from backyarders will likely translate into a smaller but more profitable industry. The environmental impact will be reduced resulting in an improved industry reputation. However, because of the shift in the business model that the industry may need to follow
Figure 6.3: Updated Causal Loop Diagram of Premises Area Size

Figure 6.4: Updated Causal Loop Diagram of the Workforce
there will be a drop in the number of new backyarders and a surge in the rate of folding of legitimate businesses and backyarders. No additional codes are needed to represent this effect; however, the Licensing and Enforcement and Backyarders Folding/Legitimisation rates need to be linked (Figure 6.5).

6.2.2 Scenario B - How it should be

6.2.2.1 ELV Supply Sector

The identified effect "Level playing field, Backyarders removed" can be interpreted as follows. Like Scenario A, Reduction of the number of operators, through the removal of backyarders will lessen ELV demand, which translates in lower ELV purchase costs. Because the changes in values occur in the industry image and reputation sector, no additional codes are needed to represent this effect.

6.2.2.2 Demand for Used Parts Sector

The identified effect "Increased demand, Good value" can be interpreted as follows. Participants assume that demand for used parts will increase dependant on the affordability of new vehicles. The identified code to add to the Demand for Used Parts variable is Marginal Demand for Used Parts (Figure 6.6 on the following page).
6.2.2.3 Premises Sector

The identified effect "Larger premises, Productivity" can be interpreted as follows. Increase premises size to cope with higher turnover, expand the business into other localities, or invest in process improvement. The three effects can be translated through an increment in costs and premises area size. The identified codes are (Figure 6.7 on the next page):

- Marginal Premises Costs to add to Premises Costs variable.
- Marginal Premises Growth to add to Premises Area Size.

6.2.2.4 Workforce Sector

The identified effect "More staff required, Higher waged attracting people to industry" can be interpreted as follows. Because of higher demand for used parts and the availability of ELVs on the market, the industry will need to grow its workforce to cope with the perceived increased demand and might have to increase wages to attract more people to the industry. The effect of significantly increasing wage costs may impact on industry profits in the long run. The identified code to add to the Workforce Costs variable is Marginal Workforce Costs (Figure 6.8 on the facing page).
6.2. QUALITATIVE MODEL

Figure 6.7: Updated Causal Loop Diagram of Premises Area Size under Scenario B

Figure 6.8: Updated Causal Loop Diagram of the Workforce under Scenario B
6.2.2.5 Industry Image Sector

The identified effect "Image improvement, Environmental leaders" can be interpreted as follows. A regulated industry with minimised competition from backyards will likely translate into a smaller but more profitable industry. The environmental impact will be reduced resulting in an improved industry reputation. Assumptions made in Scenario A for this sector can be carried over (Figure 6.5 on page 155).

6.2.3 Scenario C - Wild West

6.2.3.1 ELV Supply Sector

The identified effect "Auction houses unfettered, Shit fight, Bidding against anybody, eBay" can be interpreted as follows. Current trends continue as per the baseline model. No additional codes are needed.

6.2.3.2 Demand for Used Parts Sector

The identified effect "High/low, Fragmented" can be interpreted as follows. Current trends continue as per the baseline model although demand on parts will remain strong - like Scenario B. The identified code to add to the Demand for Used Parts variable is Marginal Demand for Used Parts (Figure 6.6 on page 156).

6.2.3.3 Premises Sector

The identified effect "No licensing or regulation, Land tax we pay, Backyarder does not", Trade waste agreements "can be interpreted as follows. Current trends continue as per the baseline model. No additional codes are needed.

6.2.3.4 Workforce Sector

The identified effect "Business not OHS standards, Open to undesirables" can be interpreted as follows. Current trends continue as per the baseline model. No additional codes are needed.

6.2.3.5 Industry Image Sector

The identified effect "People think we are Neanderthals, “uncouth”" can be interpreted as follows. Current trends continue as per the baseline model.
6.2. QUALITATIVE MODEL

6.2.4 Scenario D - Big Drama / Downward Spiral

6.2.4.1 ELV Supply Sector

The identified effect "Dramatic reduction in vehicle prices" can be interpreted as follows. With the reduction of revenue potential from ELVs as parts, both auto recyclers and backyarders will be willing to pay less for ELVs which will force down the price of ELVs. No additional codes are needed to update the CLD. However, an identified code to add in the SD model is ELV Demand Downstep.

6.2.4.2 Demand for Used Parts Sector

The identified effect "Greatly reduced" can be interpreted as follows. Demand for parts will eventually get reduced, but meanwhile, the demand for current models will decay. The identified code to add to the Demand for Used Parts variable is Demand Downshift for Used Parts (Figure 6.9).

6.2.4.3 Premises Sector

The identified effect "Downsize, sale" can be interpreted as follows. Less turnover will lead to having to scale down operations or even fold business thereby reducing the size of the premises. No change necessary as the dynamic is already captured as per the baseline model. The part about folding business is already captured because the premises area size variable is modelled as dependant on the combined
turnover of the industry. There will be a subsequent increase in combined area size because of the turnover of folded businesses being shifted to competitors/other recyclers.

### 6.2.4.4 Workforce Sector

The identified effect "Costs will outweigh sale of materials" can be interpreted as follows. Workers may require an additional skill set to cope with the shift in the line of business. This will translate into higher labour costs assuming workforce size remains the same. The identified code to add to the Workforce Costs variable is Marginal Training Costs (Figure 6.10).

### 6.2.4.5 Industry Image

The identified effect "No industry, no reputation, you don’t help people any more" can be interpreted as follows. Industry reputation will continue to decrease with no prospects for bouncing back. Environmental impact will increase with the absence of enforceable laws/guidelines. No additional codes are needed.

### 6.2.5 Observations

The scenarios and their effects on the SD model represent four possible distinct realities that the industry could face in the next decade considering the licensing and enforcement uncertainty and the ELV recyclability trend. While the effects on the baseline model vary among the scenarios, there are common elements, specifically within scenario pairs aligned with the four dimensions namely between:
• Scenarios A and B because of national enforced licensing requirements,
• Scenarios B and C because of ELV resale-ability,
• Scenarios C and D because of loose and fragmented licensing, and
• Scenarios D and A because of a throw-away of ELVs.

The scenario effects can be summarised as follows:

• Scenario A: the demand for used parts is decreased, premises and workforce costs increase, while new requirements for licensing and enforcement result in some backyarders legitimising their operations.

• Scenario B: the demand for used parts, as well as the premises and workforce costs, increase, while new requirements for licensing and enforcement result in some backyarders legitimising their operations.

• Scenario C: the demand for used parts increases.

• Scenario D: the competition for ELVs and subsequent cost of ELVs as well as the demand for used parts decrease, while costs associated with the workforce increase.

The following section explores the behaviour of the variables in the simulation model

6.3 Simulation SD Model

This section presents the plots of critical variables under the four scenarios compared to the baseline. Keeping in line with the simulation results were presented in the previous chapter, the plots and associated observations are also grouped by model sector. The observations are noted under each sector headline rather than a separate sector.

The SD model updates are tabulated in Appendix J.

It is worthwhile noting that some variables in the scenarios models exhibit an oscillating behaviour and present as unexpected or unrealistic. The reason for these oscillations that stabilise within three to five modelling cycles (years) is simple: the relatively stable system gets shocked with new conditions or values that draw some variables into their conditional thresholds resulting in some stocks being emptied or filled in a single cycle and the accorded flows re-adjusted.
In the real world of automotive recycling most of the induced conditions are applied or enforced gradually, with their effects taking almost a decade or even more to become visible or significant (e.g. changes in the vehicle composition of vehicles manufactured today will not immediately affect recyclers but perhaps in about a decade as more of these vehicles become ELVs). Hence, these oscillations in the simulation model ought to be reflective of a collapsed transient stage. The more critical and relevant aspect becomes the post-oscillations stage where most variables stabilise and delineate a trend.

6.3.1 ELV Supply, Demand, and Disposal Sector

The Australian automotive fleet, attritioned vehicles, number of ELVs in Yard, and revenue from Scrap Metal variables are not affected under the four scenarios and are therefore not presented again. The number of ELVs kept in yard per enterprise, and the scrap metal revenue per enterprise are different because the number of enterprises is different under the scenarios.

The Competition for ELVs variable (Figure 6.11 on page 163) exhibits three distinct behaviours across the scenarios. In Scenarios A and B, the behaviour follows a logarithmic increase (average 3.95% and 4.65% annual increase between 2013 and 2023 respectively). In Scenario C it follows an upward trend like that in the baseline (average 8.34% annual increase versus 8.62% for the baseline). In Scenario D, it follows a steady decrease mirroring the baseline increase pre-2013 (average 17.60% annual decline).

Like the above, the ELV Market Price (Figure 6.12 on page 163) exhibits three distinct behaviours. In Scenarios A and B, it follows a relatively flat behaviour (average annual decline of 0.42% and 0.03% respectively). In Scenario C, the behaviour closely matches that of the baseline, a slow but steady increase (1.30% average annual increase versus 1.38% for the baseline). In Scenario D, the ELV market price exhibits a downward shift before tracking a slow but steady increase which results in an overall average annual decline of 1.37%.

The ELV Purchase Costs variable (Figure 6.13 on page 164) also exhibits three distinct behaviours across the scenarios. In Scenarios A and B, it follows a relatively steady growth after an initial flat period resulting in an average annual increase of 2.52% and 2.92% respectively. In Scenario C, the behaviour closely matches that of the baseline, a steady increase (4.29% average annual increase versus 4.37% for the baseline). In Scenario D, it follows a steady increase after an initial downward shift which nets an average annual increase of 1.62%.
6.3. SIMULATION SD MODEL

Competition for ELVs

Figure 6.11: Competition for ELVs across Scenarios

ELV Market Price

Figure 6.12: ELV Market Price across Scenarios
6.3.1.1 Normalised Variables

The number of ELVs in yard per Enterprise (Figure 6.14 on page 165) -in Scenarios A, B, and C follows an upward trend like the baseline’s (average annual increases of 3.05%, 2.63% and 3.52% respectively versus 3.42% for the baseline). In Scenario D, the number is shifted upward initially then follows a similar trend to others resulting in a 5.25% average annual increase between 2013 and 2023.

The number of ELVs normalised by premises area size (Figure 6.15 on page 166) in Scenarios A, B, and C follows a trend visually similar to the baseline with an initial adjustment period followed by a downward trend. The year-on-year change in Scenario A is flat, in Scenario B and the baseline a decrease of 0.32% and 0.52% respectively, and Scenario C.

The ELV purchase costs per Enterprise (Figure 6.16 on page 166) in Scenarios A and B, increase slowly by 2.53% average annually. Under Scenario C, the costs (increasing at 4.74%) follow the baseline increasing trend of 4.73%. In Scenario D, the costs also follow an upward trend that falls between A/B and baseline/C, at 3.92% average annual increase.

Revenue from Scrap Metal Sales per Enterprise (Figure 6.17 on page 167) under Scenarios A, B, and C follows an upward trend like the baseline (average annual increases are 6.66%, 6.22%, and 7.15% versus 7.04% for the baseline). In Scenario D, an initial upward shift followed by a similar trend to other scenarios
results in an 8.94% average annual increase.

### 6.3.2 Used Parts Dismantling Sector

The parts storage density variable (Figure 6.18 on page 168) exhibits three distinct behaviours across the scenarios. In Scenarios A and D, the variable shows an initial upward shift before tracking on average respectively 20% and 45% higher but visually similar to the baseline. In Scenarios B and C, the variable drops then trends on average respectively 35% and 29% lower than but visually similar to the baseline. In contrast with the scenarios, the almost flat decreasing behaviour in the baseline is 0.29% per year between 2013 and 2023. The parts storage density only exceeds the threshold of 2.5 parts per square metre under Scenarios A and D.

The stock of dismantled parts (Figure 6.19 on page 168) in Scenarios A and D follows an upward trend increasing at 4.12% on average annually between 2013 and 2023 versus 3.03% in the baseline. In Scenarios B and C, the variable also follows almost identical trends (initial downshift then a slight increase) resulting in an overall average annual increase of 3.36% and 3.44% respectively. The differing behaviours in Scenario pairs A/D and B/C could be traced back to the marginal demand for used parts which leads to more stockpiling of parts in A/D than in B/C.
Figure 6.15: ELV Storage Density across Scenarios

Figure 6.16: ELV Purchase Costs per Enterprise across Scenarios
Revenue from the sale of parts (Figure 6.20 on page 169) in Scenarios A and D follows an identical oscillating and upward trend averaging 3.25% increase per year versus 4.22% for the baseline. In Scenarios B and C, the revenue also follows almost identical trends (initial shock upward then oscillating increase) resulting in an overall average annual increase of 9.90% and 9.99% respectively.

6.3.2.1 Normalised Variables

When normalised by the number of enterprises, the revenue from parts sales (Figure 6.21 on page 169) exhibits similar behaviour for Scenario A/D and B/C in 2013 but then diverges into distinctly increasing behaviours. The average annual increase between 2013 and 2023 under Scenarios A, B, C and D are 3.22%, 9.46%, 10.47% and 5.86% respectively versus 4.56% for the baseline.

6.3.3 Premises Sector

The premises total area size for the industry (Figure 6.22 on page 170) in Scenarios A, B, and C initially exhibits a slight decline before growing steadily. The average annual increase between 2013 and 2023 is 2.90%, 3.55%, and 2.58% respectively versus 3.31% for the baseline. In Scenario D, the initial decline is more significant than in other scenarios, resulting in an average annual increase of 1.41%.
CHAPTER 6. SCENARIOS APPLIED

Figure 6.18: Parts Storage Density across Scenarios

Figure 6.19: Dismantled Parts across Scenarios
6.3. SIMULATION SD MODEL

Revenue from Used Parts Sales

- Baseline
- Scenario A
- Scenario B
- Scenario C
- Scenario D

Figure 6.20: Revenue from Used Parts Sales across Scenarios

Revenue from Used Parts Sales per Enterprise

- Baseline
- Scenario A
- Scenario B
- Scenario C
- Scenario D

Figure 6.21: Revenue from Used Parts Sales across Scenarios
Regarding premises efficiency (Figure 6.23 on page 171) under Scenarios A and D, the variable initially exhibits a negative shock below the 2.5 threshold (due to nil/negative profits in 2013) that results in oscillations that diverge into distinct, albeit similar behaviours to the baseline. In Scenarios B and C, the initial shock is positive then crosses below the threshold but eventually stabilises in 2018 and follows a trend like the baseline.

Lastly, the costs of maintaining premises (Figure 6.24 on page 171) in Scenarios A and B, initially exhibit a slight increase over the baseline before reverting to a trend similar to the baseline. This behaviour is due to the additional marginal costs assumed due to licensing and enforcement requirements. The average annual increase between 2013 and 2023 is 3.38% and 4.03% versus 3.31% for the baseline. In Scenarios C and D, the behaviour is identical to the premises total area size variable (2.58% and 1.41% annual increase respectively).

6.3.3.1 Normalised Variables

The average area size per enterprise (Figure 6.25 on page 172) across all scenarios, initially levels off because continuing an upward trend similar to the baseline. The average annual increases between 2013 and 2023 are 2.90%, 3.09%, 3.02%, and 3.27% respectively versus 3.66% for the baseline.

The premises costs per enterprise, (Figure 6.26 on page 173) in Scenarios A
6.3. SIMULATION SD MODEL

Figure 6.23: Premises Efficiency across Scenarios

Figure 6.24: Premises Costs across Scenarios
and B, initially exhibit a slight increase over the baseline before levelling off and pursuing an upward trend like the baseline and other scenarios. The average annual increases between 2013 and 2023 are 3.37%, 3.56 and 3.37%. Whereas for Scenarios C and D, the increases are identical to the area size per enterprise variable, 3.56%, 3.02% respectively versus 3.27% for the baseline.

6.3.4 Workforce Sector

The number of workers employed by the industry (Figure 6.27 on page 174) experiences a decline in all scenarios because of nil profit initial periods. The average annual decreases between 2013 and 2023 under Scenarios A, B, C and D are 1.16%, 1.38%, 1.38% and 0.35% respectively.

Concerning workforce costs (Figure 6.28 on page 174), the variable exhibits a rebound behaviour more pronounced in some scenarios more than others. In Scenarios A and D, the average annual increase is 1.55%. Under Scenario B, the costs increase the fastest at 2.18% per year because of the added marginal workforce costs whereas Scenario C tracks with the baseline at a nominal 1% increase per annum.

As for the workforce efficiency (Figure 6.29 on page 175) under Scenarios A and D, the variable initially exhibits a negative shock below the 0.57 threshold (due to nil/negative profits in 2013) that results in oscillations that diverge into
distinct, albeit similar behaviours to the baseline. In Scenarios B and C, the initial shock is positive then crosses below the threshold but eventually stabilises in 2018 and follows a trend similar to the baseline.

6.3.4.1 Normalised Variables

The number of employees per enterprise (Figure 6.30 on page 175) in Scenarios A, B, and C experiences a drop resulting in average annual decreases of 1.14%, 1.81%, and 0.96% respectively between 2013 and 2023 versus a relatively flat increase of 0.38% for the baseline. In Scenario D, the variable exhibits a significant increase averaging 1.88% per year. Scenarios B and D represent contrasting behaviours in relation to the baseline.

The workforce costs per enterprise (Figure 6.31 on page 176) in Scenarios A and B, exhibit an initial increase resulting in an average annual increase of 1.56% and 1.76% respectively. In Scenario C, the costs track with the baseline (1.44% versus 1.34%). Whereas in Scenario D, the costs increase significantly by 3.81% per annum on average.
Figure 6.27: Workforce Size across Scenarios

Figure 6.28: Workforce Costs across Scenarios
### Workforce Efficiency

![Graph showing workforce efficiency across scenarios from 2003 to 2023. The graph includes baseline and scenarios A, B, C, and D. The threshold is marked at 0.57.](image)

**Figure 6.29: Workforce Efficiency**

### Workforce per Enterprise

![Graph showing workforce per enterprise across scenarios from 2003 to 2023. The graph includes baseline and scenarios A, B, C, and D.](image)

**Figure 6.30: Workforce Size per Enterprise across Scenarios**
6.3.5 Industry Image Sector

The plots of Enterprise, Backyarders and the total across the scenarios are presented separately. The number of enterprises variable (Figure 6.32 on page 178) in Scenarios A and B initially exhibits a slight increase then a relatively flat behaviour averaging 0.01% and 0.44% increases per annum respectively over the 2013-2023 period. The initial increases can be attributed to the adoption of licensing requirements and enforcement resulting in a significant number of backyarders switching to legitimate operations as seen in Figure 6.34 on page 179. In Scenario C, the variable follows a declining behaviour - lower than the baseline, at an average annual decrease of 0.43% versus 0.34% for the baseline. In Scenario D, the decline is more pronounced and significant, at 2.01% on average. This decline can be attributed to the high number of enterprises folding in 2014 as seen in Figure 6.33 on page 178 as a result of the industry profit dropping in the previous period due to changes in the demand for parts and subsequent revenue from parts sales.

Regarding the number of illegitimate operators (Figure 6.35 on page 179), while under Scenarios C and D the variable tracks as per the baseline due to the absence of licensing requirements and enforcement (3.73% average annual increases), in Scenarios A and B the number plummets to almost nil by 2023 (average annual decreases of 26.07% and 33.06% respectively). The number of
created backyarders drops significantly while the backyarders creation rate rises as seen in Figure 6.36 on page 180.

By combining both variables above, the total number of recyclers (Figure 6.37 on page 180) exhibits three distinct groups of behaviour. In Scenarios A and B, the variable initially drops before stabilising and averaging 1.39% and 1% annual decrease. In Scenario C, the variable tracks lower than but close to the baseline at a 0.30% average increase versus 0.38% for the baseline. In Scenario D, the combined total of automotive recyclers drops initially then exhibits a rebound averaging 0.81% over the 2013-2023 period.

The reputation of the industry (Figure 6.38 on page 181) across all the scenarios initially exhibits an oscillating behaviour due to initial periods of nil/negative profit but eventually stabilises in 2018 into visually similar but distinct trends. The variable is highest under Scenario B, followed by Scenarios A, D, C and the baseline. It is worthwhile noting that the industry reputation under Scenario D appears in 2017 as the highest than other scenarios, but this oddity could be attributed to the way the variable is calculated and how the model responds to changes resulting in oscillations to the profit and revenue variables.

The environmental impact of the industry (Figure 6.39 on page 181) exhibits three distinct groups of behaviours. Under Scenarios A and B, the variable drops to almost zero, averaging 26% and 37.91% decreases per annum respectively. In Scenario C, the variable trends along with the baseline (4.29% versus 4.37% annual increase). In Scenario D, the variable initially increases then continues an upward trend averaging 6.05% increase annually.

6.3.5.1 Normalised Variables

It is interesting to highlight the environmental impact per enterprise as plotted in Figure 6.40 on page 182. The variable exhibits behaviours not too dissimilar from the industry’s environmental impact (Figure 6.39 on page 181) with the three groups of behaviour. In Scenarios A and B, the average annual decreases are 25.92% and 39.04% respectively. In Scenario C the average increase is 4.65% running close to the baseline’s 4.44%. Of interest is Scenario D where the average annual increase is 8.86% which is almost 46% higher than the industry’s annual rate of increase. By comparison, the disparity in annual variation between the industry and normalised environmental impacts is only around 3% for Scenarios A and B, about 8% for Scenario C, and under 2% for the baseline. The cause for this disparity can be attributed to the way the environmental impact is calculated.
Figure 6.32: Enterprises across Scenarios

Figure 6.33: New and Folded Enterprises across Scenarios
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Figure 6.34: Backyarders Legitimised into Enterprises across Scenarios

Figure 6.35: Backyarders across Scenarios
Figure 6.36: New and Folded Backyarders across Scenarios

Figure 6.37: Enterprises + Backyarders across Scenarios
6.3. SIMULATION SD MODEL

Industry Reputation

![Graph showing Industry Reputation across Scenarios]

Figure 6.38: Industry Reputation across Scenarios

Environmental Impact

![Graph showing Environmental Impact across Scenarios]

Figure 6.39: Environmental Impact across Scenarios
and the high number of enterprises folding under Scenario D.

6.3.6 Financial Sector

The revenue of the industry (Figure 6.41 on page 183) in all scenarios follows an oscillating upward trend. The variable in Scenarios A and D tracks at a lower level, by approximately 11% in the 2019-2023 period than the baseline which can be attributed to lower revenue from part sales because of the negatively shifted demand for parts. Under Scenarios B and C, the industry revenue initially exhibits oscillations that stabilise by 2018 and track along the baseline.

Concerning industry profit (Figure 6.42 on page 183), the variable initially exhibits oscillations across all scenarios before stabilising around 2018 and continues an upward trend, with Scenarios A and C almost matching the baseline by 2023. Scenarios B and D track on average 31.25% higher than the baseline in the 2019-2023 period.

6.3.6.1 Normalised Variables

The profit revenue ratio (Figure 6.43 on page 185) in all scenarios exhibits initial shock oscillations that eventually stabilise by 2018 into three distinct trends visually similar to the baseline. Scenarios A and C trend closer - slightly higher
Figure 6.41: Industry Revenue across Scenarios

Figure 6.42: Industry Profit across Scenarios
than the baseline, both within 3.5% of the baseline, over the 2019-2023 period. Scenarios B and D trend 24% and 47% respectively higher than but also similar to the baseline.

Regarding the revenue per enterprise (Figure 6.44 on page 185), the variable exhibits initial oscillations that eventually stabilise by 2018 into four distinct trends visually similar to the baseline. Scenarios A and B trend 12.36% and 7.05% lower than the baseline, while Scenarios C and D 1.12% 9.48% higher than the baseline. The profit per enterprise (Figure 6.45 on page 186) follows similar behaviours to the revenue per enterprise, with Scenario A trending 5.62% lower than the baseline, and Scenarios B, C and D trending 19.19%, 6.60% and 62.57% higher than the baseline respectively.

Normalising the revenue by the number of disposed ELVs (Figure 6.46 on page 186) results in two clusters: the variable, in Scenarios A and D, eventually trends 9.58% lower than but visually similar to the baseline. Under Scenario B and C, the trends are within 0.01% of the baseline. Furthermore, the normalised profit per disposed ELVs (Figure 6.47 on page 187) eventually yields four distinct but visually similar trends to the baseline. While under Scenario A the variable trends 2.61% lower than the baseline, under Scenarios B, C, D, the trends are respectively 28.22%, 5.43%, and 34.27% higher than the baseline.

The ratio of the revenues from the parts to the scrap metal sales across all scenarios (Figure 6.48 on page 187) exhibits a declining behaviour similar to the baseline despite initial adjustment oscillations. In Scenario A and D, the variable trends 10.75% lower than the baseline. Whereas under Scenarios B and C, the variable trends within 0.02% of the baseline.

Lastly, the ratio of ELV purchase costs to the premises and workforce costs (Figure 6.49 on page 188) exhibits varying behaviours across the scenarios all resulting in net annual increases of 0.31%, 0.11%, 2.71%, and 0.17% respectively over then 2013-2023 period versus 2.52% for the baseline. In Scenarios A and B, the variable trends 18.92% and 21.22% lower than the baseline. In Scenarios C and D, the trends are respectively 2.19% higher and 23.97% lower than the baseline.

6.4 Observations Summary

This section provides a summary of observations about the qualitative and simulation scenario-based SD models. These observations are further analysed and
6.4. OBSERVATIONS SUMMARY

Figure 6.43: Industry Profit to Revenue Ratio across Scenarios

Figure 6.44: Enterprise Revenue across Scenarios
Figure 6.45: Enterprise Profit across Scenarios

Figure 6.46: Revenue per ELV across Scenarios
6.4. OBSERVATIONS SUMMARY

Figure 6.47: Profit per ELV across Scenarios

Figure 6.48: Ratio of Parts to Scrap Metal Revenues across Scenarios
6.4.1 Qualitative Model

The scenario effects in the qualitative model can be summarised as follows:

- **Scenario A**: the demand for used parts decreases, costs of premises and workforce increase, while new requirements for licensing and enforcement lead to some backyarders legitimising their operations.

- **Scenario B**: the demand for used parts, as well as the premises and workforce costs all increase, while new requirements for licensing and enforcement result in some backyarders legitimising their operations.

- **Scenario C**: the demand for used parts increases.

- **Scenario D**: the competition for ELVs and subsequent cost of ELVs as well as the demand for used parts decrease, while costs associated with the workforce increase.

Figure 6.49: Ratio of ELV Purchase Costs to Premises and Workforce Costs across Scenarios
discussed in the following chapter.
6.4. Simulation Model

Based on the analysed effects of the scenarios on the model sectors, the updates to the simulation model touched all sectors except the Financial sector. In Scenarios A and B, the effects impact all areas except the ELV Supply sector. In Scenario C the effects are limited to the Used Parts Dismantling Sector. In Scenario D the effects are limited to the ELV Supply, the Used Parts Dismantling, and the Workforce sectors.

The simulation model updates, no matter how subtle, eventually affected the behaviour of several other variables in the other sectors, e.g. Scenario C where only two variables were changed. This observation comes as expected because the model sectors are dynamically interlinked through multiple variables as indicated in Section 6.2.7.

The following observations about the scenarios provide a descriptive narrative, comparing the behaviour of critical variables under each scenario to the baseline model. All percentage difference figures are rounded averages of the difference to the baseline values over the 2019-2023 period.

6.4.2.1 Scenario A - Smart Auto Waste

Industry-level The competition for ELVs drops significantly (-30%) causing the ELV market price, and subsequent ELV purchase costs to drop (-16%).

Regarding parts dismantling, the parts storage density is higher (20%) as more parts (13%) are stocked. The revenue from used parts sales is lower (-11%).

The total area size of the premises is lower (-6%), while the premises efficiency and costs of premises are marginally lower, (-2%) and (-1%) respectively.

The size of the workforce and the workforce efficiency are lower (-12%) and (-8%) while their costs are higher (6%).

The number of enterprises marginally increases (3%), of the backyarders plummets (-96%), and the resulting total number of recyclers decreases significantly (-17%). The industry reputation is significantly higher (59%) while the environmental impact is significantly lower (-96%). It is worth noting that a total of 51 backyarders, or (36%) of the backyarders in 2012, legitimise their operations.

Concerning the industry financials, while the revenue is lower (-10%), the profit only marginally lower (-3%) resulting in a marginally higher profit to revenue ratio (3%).
Enterprise-level  The number of ELVs turned over, and subsequent revenue from scrap metal sales are marginally lower (-3%) while the ELV purchase costs per enterprise are significantly lower (-19%).

The revenue from used parts sales is lower (-13%).

The premises area size is larger (8%) while the associated costs are marginally lower (-2%).

The workforce size is smaller (-15%) while the costs are marginally higher (3%).

The environmental impact per enterprise is significantly lower (-96%).

Regarding the enterprise financials, the revenue and profit are lower, (-12%) and (-6%) respectively.

Other Dimensions  The revenue and profit per ELV are lower, (-10%) and (-3%) respectively. As for the revenue ratio from the sale of parts to scrap metal is lower (-11%) while the costs ratio of the ELV purchases to premises/workforce decreases significantly (-19%).

6.4.2.2 Scenario B - How it should be

Industry-level  The competition for ELVs significantly weakens (-27%) causing the ELV market price and subsequent ELV purchase costs to become lower (-13%).

Concerning parts dismantling, the parts storage density is significantly lower (-35%) as significantly fewer parts are stocked (-35%). The revenue from used parts sales does not differ significantly.

The total area size of the premises does not differ significantly while the premises efficiency is significantly lower (-22%) and the costs of premises are marginally higher (5%).

The size of the workforce decreases (-15%) while the workforce efficiency and costs are both higher (13%).

The number of enterprises increases (8%), of the backyarders plummets (-98%), and the resulting total number of recyclers decreases (-14%). The industry reputation is increased significantly (93%) while the environmental impact decreases significantly (-99%).

It is worth noting that a total of 57 backyarders, or (40%) of the backyarders in 2012, legitimise their operations.

Regarding the industry financials, while the revenue remains the same, the
profit is significantly higher (28%) resulting in a significantly higher profit to revenue ratio (24%).

**Enterprise-level** The number of ELVs turned over, and subsequent revenue from scrap metal sales are lower (-7%) while the ELV purchase costs per enterprise are significantly lower (-20%).

- The revenue from used parts sales is lower (-7%).
- The premises area size is smaller (-7%) while the costs marginally drop (-2%).
- The workforce size shrinks (-15%) while the costs are marginally higher (5%).
- The environmental impact per enterprise is significantly lower (-99%).

Concerning the enterprise financials, the revenue is lower (-7%) while the profit is higher (19%).

**Other Dimensions** The revenue per ELV remains about the same, but the profit per ELV is significantly higher (28%). As for the revenue ratio from the sale of parts to scrap metal remains almost unchanged while the costs ratio of the ELV purchases to premises/workforce is significantly lower (-21%).

**6.4.2.3 Scenario C - Wild West**

**Industry-level** The competition for ELVs weakens marginally (-3%) causing the ELV market price and subsequent ELV purchase costs remain about the same.

Concerning parts dismantling, the parts storage density is significantly lower (-29%) as significantly fewer parts are stocked (-35%). The revenue from used parts sales does not differ significantly.

- The total area size of the premises is lower (-8%) while the premises efficiency is higher (15%) and the costs of premises are lower (-8%).
- The size of the workforce is lower (-15%) while the workforce efficiency is higher (5%) and the costs remain about the same.
- The number of enterprises is marginally lower (-1%), of the backyarders remains unchanged, and the resulting total number of recyclers is marginally lower (-1%). The industry reputation is marginally higher (3%) while the environmental impact is marginally higher (1%). In the absence of licensing requirements, no backyarders convert their operations into legitimate enterprises.

Regarding the industry financials, while the revenue remains the same, the profit is significantly higher (28%) resulting in a marginally higher profit to revenue ratio (3%).
Enterprise-level  The number of ELVs turned over, and subsequent revenue from scrap metal sales are marginally higher (1%) while the ELV purchase costs per enterprise are marginally lower (-1%).

The revenue from used parts sales is marginally higher (1%).

The premises area size and the associated costs are higher (7%).

The workforce size is significantly smaller (-14%) while the costs are marginally higher (1%).

The environmental impact per enterprise is marginally higher (2%).

Concerning the enterprise financials, the revenue and profit are marginally higher, respectively (1%) and (6%).

Other Dimensions  The revenue per ELV remains about the same, but the profit per ELV is slightly higher (5%). As for the revenue ratio from the sale of parts to scrap metal remains almost unchanged while the costs ratio of the ELV purchases to premises/workforce is marginally higher (2%).

6.4.2.4 Scenario D - Big Drama / Downward Spiral

Industry-level  The competition for ELVs plummets (-84%) causing the ELV market price, and the subsequent ELV purchase costs to decrease (-12%).

Concerning parts dismantling, the parts storage density is significantly higher (44%) as slightly more parts are stocked (13%). The revenue from used parts sales is lower (11%).

The total area size of the premises decreases significantly (22%) while the premises efficiency is significantly higher (71%) and the costs of premises decrease significantly (-22%).

The size of the workforce is lower (-4%) while the workforce efficiency and costs are respectively significantly higher (27%) and higher (6%).

The number of enterprises is lower (-17%), of the backyarders unchanged, and the resulting total number of recyclers is lower (-14%). The industry reputation is significantly higher (35%) while the environmental impact is higher (21%). In the absence of licensing requirements, no backyarders convert their operations into legitimate enterprises.

Regarding the industry financials, while the revenue is lower (-10%), the profit is significantly higher (34%) resulting in a significantly higher profit to revenue ratio (47%).
6.4. OBSERVATIONS SUMMARY

**Enterprise-level** The number of ELVs turned over, and subsequent revenue from scrap metal sales are significantly higher (21%) while the ELV purchase costs per enterprise are significantly lower (-27%).

- The revenue from used parts sales is higher (8%).
- The premises area size and the associated costs are higher (5%).
- The workforce size is larger (16%) while the costs are marginally higher (1%).
- The environmental impact per enterprise is significantly higher (47%).

Concerning the enterprise financials, the revenue is higher (9%) while the profit is significantly higher (63%).

**Other Dimensions** The revenue per ELV is lower (-10%), but the profit per ELV is significantly higher (34%). As for the revenue ratio from the sale of parts to scrap metal is lower (-11%) while the costs ratio of the ELV purchases to premises/workforce is lower (-24%).

**Conclusions**

This chapter, which concludes the results part of the thesis, presented the SP workshop results, the effects of the identified scenarios on each sector of the SD model, the simulation results of critical variables in the scenario-based SD models, and comparative observations about these behaviours. The following chapter provides further discussion of significant findings/results organised by theme as well as the modelling approach and this research.
Chapter 7

Discussion

Given that this research is inductive and did not begin with a set of hypotheses, this chapter aims to, summarise and interpret the findings while addressing some of the critical questions raised in the introduction, indicate practical implications, reflect upon the research approach while pointing to the limitations, and provide suggestions for future research.

Section 7.1 emphasises that the network of automotive recycling enterprises in Australia should be viewed as a complex system, and argues that applying simple policy instruments to automotive recycling in the pursuit of arbitrary targets (e.g. recycling rates) could result in unintended consequences such as the cases of the EU and Japan. The diversity in the dismantlers business models and the multitude of revenue streams are highlighted.

Section 7.2 focuses on the issue of the backyarders regarding competition with legitimate enterprises, the environmental impact of operations and the reputation of the industry. The section postulates that a nationally harmonised and enforced dismantler licensing requirement may be essential in curbing competition from the backyarders, a reduction in the environmental impact (at industry and enterprise level) and betterment of industry reputation.

Section 7.3 highlights the effects of the automotive manufacturers adopting and promoting parts reuse on the automotive recycling industry and the subsequent environmental impact.

Section 7.4 highlights the benefits of adopting MDM as a business strategy to supplement the automotive recyclers revenue and profit while reducing the environmental impact. The section also suggests a business model for standalone enterprises specialising in ELV material segregation using MDM.

Section 7.5 compares the Australian ELV situation to that in Taiwan drawing...
7.1 ELV Recycling: A Complex System

In this section, the diversity of the business models of automotive dismantlers and their revenue streams (Section 4.1.3) are highlighted to emphasise the need to treat the system of automotive recycling in Australia as a complex system.

As shown earlier and concerning the business models, an Australian automotive recycler or dismantler may belong to one of three broad categories: small-scale, large-scale, or mid-range. All dismantlers share a strategy of maximising revenue and profit.

However, each category operates under different business models relying on a multitude of revenue streams. For example, the small-scale operators perceive dismantling as a secondary business activity and the sale of dismantled parts as a minor income stream. Meanwhile, the mid-range operators primarily dismantle ELVs and rely heavily on part sales. The large-scale recyclers generate most of their income from parts and scrap metal sales and regard other automotive business activities (e.g. servicing, mechanical repairs) too insignificant to warrant further investing in them (e.g. hiring a mechanic, setting up a workshop repairs area).

Fluctuations in scrap metal prices could significantly impact large-scale operators while small-scale and mid-range dismantlers are unaffected.

Conversely, a shift in motorists preferences for used vehicle purchase, repair or service at the automotive dealers’ network over independent dealers or mechanics could significantly impact the revenue of small-scale operators. The mid-range and large-scale dismantlers may not be as affected as they cater to different segments (e.g. insurance repairs, DIY repairs).

This contrast in business models and subsequent revenue streams means that:

- different categories may be susceptible to different market trends or forces and at different rates,
- responses of operators to these changes in the form of adjustments to operations may be different, and
• effects of these responses, whether individual or collective, may come at the
detriment of other operators.

Adding to the above the competition from outside and within the industry, it is
safe to conclude that the system of ELV recycling needs to be treated, not just as
a complex system Field et al. (1994) but more importantly as a pluralist complex
(Flood and Jackson, 1991) which calls for the involvement for different groups of
stakeholders in determining policy options.

The cases of ELV-related policy failings or unintended consequences high-
lighted in Section 2.3 become then expected rather than surprising as they appear
to have disregarded the complex nature of the dismantling systems in the respect-
ive countries and focused instead on other problematic issues (e.g. handling of
hazardous waste, waste going to landfill, ELV recyclability). This perspective
questions the initial scoping of the problems that led to these policies, irrespec-
tive of the intentions or the aims of these policies.

7.2 ELV Recycling Licensing Policy Domain

This section discusses the effects of a nationally mandated and enforced licens-
ing policy for automotive recyclers. However, first, it is essential to emphasise
the effects of the lack of a policy concerning the issue of backyarders. The SD
simulation model results suggest that if left unchecked, the growing pool of back-
yarders competing with legitimate operators creates three issues to the industry
in addition to the daily operational challenges:

1. At the supply side of ELVs, the ELV market price and subsequent ELV pur-
chase costs are higher. The baseline figures (Figure 5.14 on page 130 and
Figure 5.39 on page 143) suggest that a doubling in the number of back-
yarders coincides with a 20% increase in ELV market price approximately,
perhaps due to the additional speculation from having more backyarders at
salvage auctions. Given that the ELV purchase costs are the most signific-
ant component of the business costs (Figure 6.49 on page 188), operators
particularly those with limited liquidity position may be driven out of busi-
ness. As a result, the industry will likely see a decrease in the number of
enterprises as seen in the baseline, as well as in scenarios C and D (Figure
6.32 on page 178).

2. Environmentally, the presence of backyarders, disregarding fundamental
environmental protection laws and regulations, significantly increase the
overall impact of dismantling, at least 130% higher environmental impact over the model horizon in the baseline, as seen in scenarios C and D (Figure 6.39 on page 181). Further complicating the matter is the lack of regulations overseeing and auditing automotive dismantlers.

3. On the industry image front, the reputation of the industry is perceived as worsening. The simulation SD model suggests that the reputation is almost flat. The model formulation is tied to the industry profit-revenue ratio and the number of enterprises (H). A smaller highly profitable industry may be more reputable, and therefore more attractive for backyarders to establish operations.

Put differently, the industry views the backyarders, not only as an economic threat but also as a threat to the environment and industry reputation in the absence of an overall policy on licensing requirements and enforcement. The effects of this policy were explored in Scenarios A and B qualitatively (sections 6.2.1 and 6.2.2 respectively), quantitatively (section 6.3), and compared to the baseline model (sections 6.4.2.1 and 6.4.2.2). To help illustrate the policy effects, the following shortlist aggregates both scenarios and represents the effects of mandating a nationally harmonised and enforced dismantler licensing policy. The percentage difference over the baseline is averaged over the two scenarios, rounded up to the nearest digit and displayed between brackets:

- **Industry-level:** the number of enterprises increases (6%), of backyarders plummets (-97%), and the resulting total number of recyclers decreases significantly (-16%). The industry reputation is significantly higher (76%) while the environmental impact is significantly lower (-98%). A total of 54 backyarders, or (38%) of the backyarders in 2012, legitimise their operations. The competition for ELVs drops significantly (-29%) causing the ELV market price and subsequent ELV purchase costs to drop (-15%). The profit to revenue ratio in the last five years of simulation is higher (13%).

- **Enterprise-level:** the ELV purchase costs per enterprise are significantly lower (-20%). The environmental impact per enterprise is significantly lower (-98%).

- **Other Dimensions:** the costs ratio of the ELV purchases to premises/workforce decreases significantly (-20%).
The observations above support the case for pursuing the suggested policy, despite the added costs of licensing, staff training and increased wages, and regardless of the vehicle recyclability dimensions which will be discussed in the following section.

### 7.3 Vehicle Recyclability Domain

This significant uncertainty was identified in the SP workshop and explored further through the SD model scenarios. It is hypothesised that current automotive manufacturing trends may be closer to material recyclability instead of parts reuse which may be shifting the profile of the automotive parts toward a throw-away product instead of one that could be easily dismantled and re-purposed.

Conversely, if the automotive manufacturers were to pursue an alternative strategy focusing on parts reuse then the effects on the automotive recycling industry could be noticed. Such a shift was explored in Scenarios B and C qualitatively (sections 6.2.2 and 6.2.3 respectively), quantitatively (section 6.3), and compared to the baseline model (sections 6.4.2.2 and 6.4.2.3). The following shortlist represents the effects of maximising the parts reusability at the design and manufacturing level on the automotive recycling industry. The percentage difference over the baseline is averaged, rounded up to the nearest digit and displayed between brackets:

- **Industry-level**: the number of enterprises increases (4%), of backyarders plummets (-49%), and the resulting total number of recyclers decreases (-8%). The industry reputation is higher (48%) while the environmental impact is lower (-49%). A total of 29 backyarders, or (20%) of the backyarders in 2012, legitimise their operations. The competition for ELVs drops significantly (-15%) causing the ELV market price and subsequent ELV purchase costs to drop (-7%). The profit to revenue ratio is significantly higher (24%).

- **Enterprise-level**: the ELV purchase costs per enterprise are lower (-11%). The environmental impact per enterprise is significantly lower (-49%).

- **Other dimensions**: the costs ratio of the ELV purchases to premises/workforce decreases (-10%).

As the figures suggest, improving the parts reusability at the design and manufacturing stage could positively impact the automotive recycling industry commer-
7.4 ECONOMIC AND ENVIRONMENTAL VIABILITY OF MDM

7.4.1 Economic and Environmental Viability of MDM

Despite a continuing of the current industry practice and the far-from-ideal regulatory oversight, machine-based dismantling may be a viable option for improving the industry revenue while reducing the environmental impact of dismantling. However, the environmental viability of the MDM is dependent on the GHG factor of the energy source as it helps determine the environmental impact of using compared with typical shredding. Also, current trends in vehicle lightweighting through the use of lighter materials (Tucker, 2013) may decrease the...
The results from the dismantling trials support the economic and environmental benefits of integrating MDM into the operations of mid-scale operators. Even more so, the modelling suggests an opportunity for new entrants in the automotive recycling industry specialising in material segregation using MDM. Regarding the reverse cycle chain of vehicles, these new recyclers would be positioned between the automotive recyclers and material recyclers offering a slightly higher return for scrapped vehicles to the former, supplying the latter with recovered materials in a more streamlined and centralised fashion.

These recyclers would ideally be located in industrial zones near small automotive recyclers. Taking into account the revenue and the profit potential of adopting MDM in material segregation, about sixteen mid-tier enterprises spread around major cities and operating 24/7 could handle almost 80% of the Australian ELVs.

Tangent to MDM, recent research supports the premise that further segregation of ELVs, specifically the recovery of electronic components for profit could help supplement the revenue of automotive dismantlers Rosa and Terzi (2018).

### 7.5 Comparison with Taiwan’s ELV Situation

Thinking of the ELV regulations, a nationally mandated and enforced licensing policy for automotive recyclers in Australia is perhaps most reminiscent of the pursued policy in Taiwan in the 1990s (Wen et al., 2009).

Despite Australia and Taiwan vastly differing concerning the area size, automotive fleet size, new car sales, number of ELVs generated, and subsequently the severity of the ELV situation* (2.08 vs 47.23 ELV$^2$ per sq km per 1000 capita), the two countries share similarities in the population size and balance of trade of new vehicles - both net importers of new vehicles.

Most importantly, the current ELV situation in Australia has striking similarities to that in Taiwan before the implementation of the “End-of-life Vehicle recycling guidelines” in 1994: an unregulated non-standardised industry with unlawful operators and the mostly unknown fate of disposed of ELVs (Wen et al., 2009).

As discussed earlier in Chapter 2, in contrast to the other ELV management policies (Sakai et al., 2014), Taiwan’s approach placed a stronger emphasis on the

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*For an overview of these indicators refer to Table 2.1 on page 24.
licensing, auditing of and the reporting of automotive recyclers. Much like the findings of this research suggest concerning the Australian industry.

The Taiwanese experience is thus most relevant to the Australian situation, taking into consideration the insights gained in this research particularly regarding the proposed policy approach centred on mandated licensing for automotive recyclers. It represents an action path supported by evidence that Australia could pursue to regulate the automotive recycling industry.

The practical recommendations presented in the next section further explore the actions that the Australian automotive recycling industry, business and governments should consider to address the ELV recycling issue in Australia.

## 7.6 Practical Recommendations

Going back to the identified scenarios, it appears that Scenario B: How it Should Be, represents an ideal situation that may help achieve positive benefits to the automotive recycling industry and the environment. However, it would be unrealistic to expect policies and strategies could merely be adopted, enacted upon and enforced. However, assuming that the automotive recycling industry comes to terms or reaches consensus with the particularities of the scenario, it could take years to negotiate and develop specific policies with the federal, state and local governments.

Furthermore, convincing the automotive manufacturers to improve the parts reusability in newer solely to adhere to an Australian requirement could prove challenging if not impossible given:

- the counter-trend by manufacturers towards maximum material recyclability (Dalmijn and Jong, 2007), as opposed to maximum parts reuse, to adhere to the ELV directives and regulations in the EU and Japan where the combined total of new car sales is almost 20 million units (OICA, 2016), and

- the relatively small size of the Australian automotive market (declining from 1.74% of the global new car sales in 2005 to 1.33% in 2016 (OICA, 2016)) and consequently limited leverage on the auto manufacturers to propagate a global shift in automotive design (FCAI, 2014).

Nonetheless, and given the external impediment, the automotive recycling industry in Australia should pursue national licensing requirements specific to auto-
motive recycling as the simulation model suggests that commercial and environmental benefits could begin to show in as little as three years from adoption.

Some practical policy recommendations and considerations for the stakeholders in the industry are discussed below by tier level (industry, business, government). The recommendations are based on observations from the SI, SP workshop and modelling.

7.6.1 Industry Level

The automotive recycling industry needs to improve its image due to its effect on profitability. The industry image has two main issues, the number of non-legitimate operators and resulting competition, and the lack of standards in ELV waste handling.

With regards to the number of non-legitimate operators, the industry needs to leverage its relationship with the auction houses as well as relevant government bodies to curb down the ability of non-legitimate operators bidding for the same ELV stock at the auctions. The approach needs to be an inclusive and collective effort.

As for the second issue, the lack of a standard in the handling of ELVs and the resulting waste, the industry needs to adopt a national code of practice for dismantling which is attainable and unburdening to even the smallest recyclers (could be based on APRAA’s code of practice). Depending on the level of involvement from APRAA and ability to restructure, an independent agency -similar to Taiwan’s RFMB, may need to be established to administer and audit the licensing and enforcement of the code. The agency could be funded partly from:

- a recurring registration fee paid by the recyclers to their respective automotive industry association,
- a small fee paid by the motorists with each vehicle registration and renewal, and partly from
- a nominal fee levied per vehicle from manufacturers and their importers (which ought not to be passed onto the consumer).

This code of practice may then be promoted to become a requirement for backyards intending to register as legitimate automotive recyclers. It is hoped that by sharing the economic costs of licensing and enforcement among the respective stakeholders, the costs will be less of a burden to any single entity. It is
also hoped that the dismantlers will be motivated to adhere to the code requirements and that the automotive manufacturers take more into consideration parts reuse/recyclability.

7.6.2 Business Level

At the business level, several strategies could be pursued for a more sustainable industry most revolving around the improvement of resource use, revenue and image, namely:

- Diversifying business operations to include other revenue streams\textsuperscript{1} such as providing mechanical repairs, parts replacement service, and using MDM for further material segregation.

- Specialisation in certain brands or models. This approach may appear at first limiting given the current market for spare parts. However, it could help improve the business image as it ties it to a popular product or brand image. The interviewed specialised auto recyclers appeared to have robust business processes and turnover despite serving a market niche.

- Adopting a transparent monitoring and reporting mechanism towards the reduction of environmental impact of ELV handling and dismantling.

- Improving, and more importantly publicising the effort to, the dismantling process by:
  
  - upgrading the facilities or the procurement of equipment for hazardous materials containment.
  - adopting a decontamination process.
  - providing training to staff and improving their wages.
  - minimising unnecessary dismantling and stockpiling of parts.
  - maximising the use of space and improving storage capability.
  - accelerating ELV procurement and removal: the longer an ELV remains on the premises, the higher the associated storage costs.

\textsuperscript{1}If the operator is reliant on a single stream of income.
7.6.3 Government Level

When considering policy options for the Australian system, the stakeholders particularly at the policy level, need to take into account the following factors:

- The complexity of the system.
- The lack of the waste-related drivers seen in other countries (landfill space, the volume of landfilled ELV waste).
- The comparatively low incidence of vehicle abandonment and car theft unlike in other countries such as New Zealand and Japan.
- The low population density and the more prolonged use of vehicles (as evidenced in the higher average age of ELVs in Australia).
- The effectiveness (or lack of) and unintended consequences of other countries ELV policies.

When designing and implementing a licensing automotive recyclers policy, the policymakers need to consider a PS or shared responsibility framework (in contrast with Taiwan’s EPR model) whereby the primary stakeholder groups in the automotive biosphere contribute to and benefit from the scheme. The aim is to cause a minimal financial burden on each entity group and minimise the environmental impact of the dismantling activity (as well as the activities surrounding ELV dismantling). The interests of various stakeholder groups need to be considered, particularly with the long-term sustainability of the industries and workers. For better comprehensiveness, the stakeholder groups identified in Section 2.4.1 should be engaged in the policy consultation and development processes.

The policymakers may find useful the information presented in this study. However, engaging with various groups of stakeholders to better understand the issues is an absolute must. Merely borrowing policy mechanisms from other countries or jurisdictions could result in unintended consequences and may prove ineffective (Sterman, 2000).

Lastly, information control is of paramount importance to assess compliance and policy effectiveness. Data collection mechanisms and processes at the business and industry levels need to be designed and implemented from the outset of any policy undertaking.
Chapter 8

Conclusion

This chapter highlights the study limitations, main contributions and paths for further research.

8.1 Study Limitations

Despite the insights gained, and much like many research endeavours, this research faced several limitations - specific to the SD model and methodology-wise.

8.1.1 SD Model

The model assumes that no matter how large the pool of backyarders grows, the industry maintains the same control over the stock of available ELVs and the market share of used parts sold. This assumption is based on interview notes indicating that the backyarders generally cause the final price of ELVs at auctions to increase while buying a small number of ELVs and consequently holding little ELV stock to cause a noticeable disturbance to the price and supply of used parts.

It is worth mentioning, however, that the level of control on available ELV stock may be slipping away from the industry because an interviewee indicated that some backyarders have been growing their sites and operations.

Parallel to the above, the model assumes that the number of exported used parts...
cars or ELVs from Australia is insignificant. Moreover, the model assumes that the average price for a dismantled part remains static. However, recyclers vary parts prices depending on several factors, such as:

- whether additional operational costs need to be recouped to maintain or increase the profits,
- the scarcity of the part and the comparative price of a new part, and
- the need to price match or beat a competitor’s quote.

The next iteration of the SD model would capture the above dimensions and allow analysis of their effects by allowing:

- the proportion of ELVs bought and parts sold by the industry to vary depending on the number of backyarders and an estimated number of exporters, and
- the average part price to vary depending on operational costs, industry size.

### 8.1.2 Methodology

Firstly the range of stakeholders that were interviewed to arrive at the qualitative and preliminary quantitative models was constrained. If more or other stakeholders were to be involved, the identified concepts and causal links might have been affected (Baker and Edwards, 2012). Consequently, the models might have been different.

Secondly, the availability of the variables BOT data was poor. Not all variables had data available in the public domain or even collected. Moreover, for those that are available, the historical ranges and data granularity (i.e. monthly instead of yearly) were far from comprehensive which meant that the deductions or assumptions made cannot be ascertained beyond the available data points.

Thirdly, the preliminary model validation was limited to a questionnaire, presented to the SP workshop participants, that was conducted once. In an ideal situation, several workshops would have been run involving different participants to reach a greater consensus about the model, its variables and causal links.

Fourthly, The model does not explore linkages with other industries, the make-up of the automotive fleet (locally made versus important).

Fifthly, despite their significance, the inferences reached as a result of modelling scenarios and policies only represent an insight into a limited range of plausible futures awaiting the auto recycling industry in Australia.
Lastly, and regarding the methodology, the adopted data analysis techniques that were adopted and trialled in this particular application may only be regarded as experimental since it remains to be seen how effective they might be in other implementations or contexts.

8.2 Contributions and Significance

Perhaps the most significant contribution of this research lies in the grounded SD model which:

1. builds on the views of industry stakeholders through carefully designed SI and SP as qualitative data collection mechanisms.

2. could be modified with more concrete or new data and as well as new influences/variables to help the stakeholders in the industry in assessing the impact of emerging trends and proposed laws/regulations on the industry.

3. could also be adjusted to fit the business model of a single operator as a business strategy analysis tool (i.e. diversifying revenue streams or specialisation) or an environmental impact assessment tool with the integration of additional measurable variables (e.g. litres of fluids collected, quantity hazardous materials handled, energy consumption).

This research contributes to the body of knowledge in multiple areas:

- On automotive recycling analysed through SD as an ST approach, further supporting the approaches of Zamudio-Ramirez (1996), Kumar and Yamaoka (2007), and Hedayati and Subic (2011).

- On automotive recycling in Australia by:
  
  – affirming the need to treat the network of automotive recyclers as a complex system,
  
  – addressing essential information and data gaps about the industry and the Australian ELV, and by
  
  – presenting a grounded SD model developed around the operational challenges of the industry, based on qualitative SI and SP workshop data.

- On SD by:
confirming its applicability and adaptability as a research approach to tackle the issues around ELVs in specific, and generally the structurally complex systems,

– combining SI/QDA and SP to overcome information gathering difficulties and enhance the visibility and documentation of the SD modelling process.

Most of the created knowledge has already been disseminated through the publication of peer-reviewed articles and the presentation to academics and industry stakeholders at numerous conferences as per the list in the Publications section of the front matter. These articles have been purposely modified and included as various sections of this dissertation highlighted with a 'Published Work' subheading.

The insights gained from applying SD to the Australian ELV recycling industry could be useful to the industry stakeholders as it would help develop future strategies for the industry.

On the methodological level, the adapted QDA approach may be followed by SD practitioners and researchers wanting to document the rationale behind SD modelling decisions when handling qualitative data such as the causality among variables, formation of dynamic hypothesis and formulation of variables.

8.2.1 Research Aims and Objectives - Revisited

Looking back at the research aims and objectives, the following observations ensue:

1. To explore the current operational processes in the Australian automotive recycling industry and identify the issues and challenges: this research explored through the surveys and data collection, both quantitatively and qualitatively the current processes in ELV recycling as well as the factors influencing the current behaviours. The insights gained about various business models and current processes represent a reference point and a significant contribution to the body of knowledge on ELV recycling in Australia.

2. To analyse the most impending issues and challenges facing the Australian automotive recycling through qualitative and quantitative System Dynamics modelling: the research through stakeholder involvement and the grounded SD model helped identify and confirm the sustainability of the industry
8.3. **PATHS FOR FURTHER RESEARCH**

as a critical issue tied to operational challenges, namely the competition from the backyards and managing workforce and premises costs.

3. To identify the critical scenarios facing the Australian automotive recycling industry in the coming decade: through stakeholder involvement in the SP workshop, four scenarios were identified meshing a nationally harmonised and enforced licensing requirement for ELV recyclers, with the uncertainty about vehicle recyclability.

4. To study the effects of the scenarios on the Australian automotive recycling industry using the baseline model. Using an adapted qualitative data analysis method, insights gathered from the stakeholders were translated into effects on various variables and sectors of the SD model, enabling to assess the impact of the licensing policy and improving vehicle recyclability.

5. To propose a policy or a strategy that improves the financial sustainability and reduces the environmental impact of the Australian automotive recycling industry: the recommendations presented in this chapter along with the assessment of MDM dismantling provide a practical path for the industry and involved stakeholders to pursue.

### 8.3 Paths for Further Research

There are multiple ways to pursue further research on ELVs in Australia by building on the findings of this study considering that it covers significant depth (through filling data gaps on the Australian ELV and the Australian ELV recycling industry) and breadth (from operations to business models to policy to material composition and dismantling processes).

A more detailed quantitative survey of the industry could help generate more insights about the current processes in ELV recycling. Historical data on revenue and profit, ELV turnover and labour could help further refine the SD models (both baseline and scenarios).

The inclusion of the ELV export stream into another iteration of the model coupled with interviews with ELV exporters could provide a broader view of the ELV situation in Australia. It could also help identify influencing factors driving what appears as cyclic behaviour as seen in 2.2 on page 25.

Future research could look at the linkages between the industry and related industries (crash repair, auto insurance, scrap recycling) to draw a more holistic
view about the ELV recycling industry fitting within the reverse supply chain of vehicles.

Lastly, further work is needed to explore dismantling methods, other than using MDM and electronic parts recovery, that could improve the economic prospects and long-term viability of automotive recycling in Australia and lower its environmental impact.
Appendix A

A Global Comparison of End of Life Vehicles Policies

This appendix consists of the paper as published in the proceedings of the International Conference on Sustainable Automotive Technologies in 2008 (ICSAT2008): *Meeting the Challenges to Sustainable Mobility*. The comparison looks at some of the unintended consequences of ELV policies affecting their effectiveness while calling for better data control reporting ELV movements and exports.
A GLOBAL COMPARISON OF END-OF-LIFE VEHICLES POLICIES

E. EL HALABI1, M. DOOLAN2, AND B. NEWELL3

1The Australian National University, Faculty of Engineering, Canberra, ACT 2601 Australia, Email: ezzat.elhalabi@anu.edu.au
2The Australian National University, Faculty of Engineering, Canberra, ACT 2601 Australia, Email: matthew.doolan@anu.edu.au
3The Australian National University, Fenner School of Environment and Society, Canberra, ACT 2601 Australia, Email: barry.newell@anu.edu.au

Waste generated by End-of-Life-Vehicles (ELV) has been a driver for several industrialised countries, typically in Europe, to adopt active management policies and regulations. In this paper, we will examine the ELV policies implemented in the following countries: Germany; Japan; Sweden; Netherlands; and United Kingdom. We will present the context in which these policies were created, and highlight some of the aspects of these policies. Comparisons will be drawn between the different policies identifying and contrasting the resulting effects. We conclude by highlighting the need to address used-car-export, which can be viewed as transferring waste to other countries. We also emphasize the importance of having a reliable data collection and reporting framework for the disposal stream, as means to evaluate ELV policies effectiveness.

1. Introduction

Over the past two decades, governments in several countries around the world have been working on minimizing the car’s impact on the environment throughout its lifecycle. By setting, for example, increased fuel efficiency or stricter emission targets, legislators hope that their ever growing national car fleets will have a smaller footprint on the dwindling fossil fuel supply, and perhaps will contribute less to continuously increasing air pollution and green-house gas concentrations. Similarly, legislators who enacted End-of-Life Vehicles (ELV) policies are anticipating better extraction of materials and/or energy from ELV waste; leading to less ELV waste ending up in scarcer landfills, with the waste itself being less harmful to the environment. But, are these policies really working? Furthermore, are there policy-induced secondary effects offsetting the anticipated reductions in ELV waste and hence, making it harder to reach the intended goals?

Most recent research in the field has looked into technological and business aspects of ELV policies: such as exploring technological barriers to achieving recyclability goals (Gerrard & Kandlikar, 2007) and examining market adaptation to new regulations (Ogushi & Kandlikar, 2005) and (Unknown, 2002). There have been a number of comparative studies of countries’ specific ELV practices (Nakajima & Vanderburg, 2005), but they often concentrate on the effectiveness of these policies in a single dimension, often that of percentage reduction in waste sent to landfill. Limited research was found that analyzes secondary effects induced by these policies; the work of Kumar
and Yamaoka (2006) shows that Japan’s ELV regulation is likely to be linked to increased used car export if no remedial action is taken.

By analyzing used car export data and other statistics from a number of countries (Germany, Sweden, United Kingdom, Netherlands and Japan) that enacted ELV policies, this paper suggests that these policies are indirectly encouraging the export of ELV to other countries where ELV treatment (de-pollution, dismantling, etc.) may be environmentally unsound or non-existent. From a global environmental perspective, these ELV policies could simply be moving the ELV issue across the border. This paper also highlights the gaps between relevant data collection and reporting mechanisms that are crucial to assess the effectiveness of these policies.

2. Background and Contrast of Policies

The European Union (EU) ELV Directive of 2000 (Directive 2000/53/EC) mandated that all Member States transpose the directive into laws and regulations by April 2002. The EU ELV directive addressed several key areas in vehicle life cycle from cradle to grave. The key areas included:

- **Prevention (Relative to car manufacturers and associated suppliers):** Dictated limiting the use of hazardous materials in car manufacturing. It also set out provisions for design, dismantling, reuse and recovery. It also encouraged an increase in the use of recycled materials. Lead, Mercury, Cadmium and Hexavalent Chromium were to be banned by January 1, 2003.

- **Collection:** Provision of an adequate collection system which insures that all ELV are taken up by authorized treatment facilities. It calls for a deregistration process which issues a certificate of destruction for every dropped-off ELV. The last owner of an ELV bare no cost associated with ELV treatment, except where main parts, such as engine/transmission, of the vehicle are missing.

- **Treatment:** ELV storage and treatment must be done in an environmentally sound manner which implies regulating the treatment. The adoption of certified environmental management systems was encouraged.

- **Reuse and Recovery:** Through reuse, recovery and recycle of car parts. General targets for reuse/recovery were set at 85% by 2006, and 95% by 2015.

- **Coding standards and dismantling information:** Car manufacturers and part-makers must use component and material coding standards to help identify parts that are suitable for reuse and recovery when dismantling the vehicle. Car manufacturers must also provide dismantling information on new models and the location of hazardous materials and make the information available to authorized dismantling businesses.

The EU ELV Directive was transposed, with slight variations to recycling goals, zero liability conditions, and reporting frameworks into most member nations of the European Union. (Fergusson, 2006). However, the process has been slow even though some countries already had laws or voluntary industrial agreements that dealt with the ELV predicament (Zoboli et al., 2000); furthermore, the implementation proved problematic in
regards to measurement of recycling/reuse rates as well as on collection of associated statistics throughout the reverse supply chain (Lucas, 2001). On the other side of the world, Japan’s historical concern with landfill availability and waste generated by Automotive Shredded Residue (ASR) lead to passing the Automobile Recycling Law in 2002, which took effect from January 2005. The law covered all forms of four-wheeled vehicles irrespective of size or weight, whereas the European ELV directive only covered vehicles designed for carrying less than 9 passengers, and with gross weight of 3.5t or less. Under Japan’s ELV law, car manufacturers were assigned the responsibility of handling only ASR, Fluorocarbons, and airbags generated by ELV dismantling and shredding. Vehicle owners were to cover the cost of ELV treatment via a fee collected at the time of new car purchase, or at the time of vehicle inspection for older vehicles. The Japanese law placed heavy emphasis on the information management required for funding and reporting purposes. The law also set the ASR recycling targets to 30%, 50%, and 70% to be reached by 2005, 2010, and 2015, respectively. In addition, 85% of airbags must be recovered from the total number of ELV treated. It is worthwhile mentioning that several Japanese car manufacturers (like Nissan) have already met or exceeded the 2015 recycling targets. The EU’s ELV directive was specifically directed at standardizing the then-present (pre-1999) policies and voluntary agreements in 10 Member States, and extending this framework to other Member States. Most of those previously followed policies, as well as Japan’s Automotive Recycling Law, were originally motivated by the emerging need to reduce the car’s impact on the environment throughout its lifecycle (as part of a global move towards sustainable development Kanari et al. (2003) and Kim (2002)); another motivation factor was the desire to reduce ASR volumes ending up in landfills.

3. The Used Car Export Issue

When comparing (a) the number of ELV treated in Japan, Sweden and Netherlands, to (b) used-car export figures in these countries, a common trend is identified; that of increasing exports. Keeping in mind Janischewski et al. (2003)’s suggestion that “Old Car Regulation” or ELV regulation is an important factor driving an increase in used-car export, a correlation can be made between the years of implementation of ELV policies and an upward trend in used car export, even though Sweden and Netherlands previously had ELV regulations. In the case of Japan (Figure 1), the annual increase in used-car exports since 2002 (the year when the ELV law was passed) has been 16.7% on average (JUMVEA, 2008). In the case of Sweden and Netherlands, both of which previously had ELV legislations, once the EU’s ELV Directive was being adopted (in 2000/2001) there has been a correlated increase in used-car exports from these counties. The Netherlands ELV treatment trend could be of a concern because, while used-car exports are increasing, no comparable increase in treated ELV’s is found (Figure 3). It is interesting to note the slight decrease in treated ELV and the slight increase in used-car export in 2007 in Sweden when the ‘vehicle disposal premium’ (an incentive paid to last owner for delivering an ELV) was abolished (Figure 2).
Figures 1, 2 & 3. Logarithmic scale comparison of Japan’s, Sweden’s and Netherlands’ used cars export and ELV treatment data normalised against fleet size, and in the case of Netherlands, normalised against vehicle deregistration data (Sources for Japan JARC, JAMA, and JUMVEA; for Sweden SIKA, for Netherlands ARN).

4. Statistics Control and Information Management Issue

In the case of Germany’s used car export as shown in Figure 4, there is a significant gap between the estimates and the actual figures. While the gap can be attributed to criteria in the export-reporting criteria, it also raises concern about the adequacy of the system in tracking deregistered vehicles; compounded with absence of official figures of ELVs, this issue makes it difficult to assess the success of the ELV policy (Rainer, 2001).

There is also a similar problem in the case of the UK’s ELV de-registration figures; that is, there is a significant gap between official data on ELV treated cars (763,000 reported destroyed in 2006 via issuance of a CoD - Certificate of Destruction) and the 2 million car estimate. This indicates a major compliance-prompting revision to legislation in order to overcome the shortfall in reporting of and the operation of unlicensed dismantlers/shredders (letsrecycle.com, 2007).
5. Conclusion

Looking back at the ELV policies considered in this study, no provision was found regarding export of ELVs; as a matter of fact, the recycling fee in Japan is reimbursed to the last owner or entity if the vehicle is exported. This can be viewed as incentive to export rather than to process the vehicle locally; not to mention the obvious revenue to be derived from selling a used car into an export market.

While not all used-car exports are ELVs, we can reasonably suggest that these hidden incentives are moving the ELVs across the borders, often to countries that lack the resources and legislations for environmentally safe end-of-life treatment. Export statistics from countries analyzed in this study suggest that the bulk of used-car exports are heading to Africa (Algiers, Nigeria), and to the eastern states of Europe (Russia).

An evaluation of the success or effectiveness of ELV policies largely depends on statistical control of the ELV system, and data collection at various intervals in the disposal stream. This includes de-registration, dismantling, and shredding. It also includes an export component where whole cars, car parts and even shredded metal/residue could be shipped abroad. Reporting on implementation progress is mandatory by the EU ELV Directive, but we could not locate official statistics for Germany or UK on the number of treated ELV. Add to this is the issue of compliance (unlicensed dismantlers and shredders). Given the complexity of the mix, and the poverty of the data, it is difficult to judge whether the adopted ELV legislations around the world are delivering on their promising recycling targets, both from national and global environmental perspectives. The indications are, however, that the main aims of the ELV programs are not being met when looked at globally.

Acknowledgments

The authors would like to thank the Commonwealth of Australia and the Cooperative Research Centre for Advanced Automotive Technology (AutoCRC) for the financial support to this research. Also, the authors would like to thank Professor Aleksandar Subic for, without his vision and support, this project would not have materialized.
Appendix B

Weight Estimate of Australian ELV in 2012

This appendix provides the data tables used to estimate the average weight of the Australian ELV based on the sales data PMV and LCV sales data between 1991 and 2000 (AAI, 2009).

The proportion of sales of each segment (compact, medium sized, large, SUV and LCV) is first calculated for each year.

The proportions are then averaged for each segment.

A make model from 1995 representative of a popular model in each segment is then chosen and the weight data is sourced (IDIS2, 2014).

The average weight is then calculated based on the proportion of sales by segments and weight of the representative model.

<table>
<thead>
<tr>
<th>Year</th>
<th>Compact</th>
<th>Medium</th>
<th>Large</th>
<th>SUV</th>
<th>LCV</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991</td>
<td>151467</td>
<td>10107</td>
<td>118813</td>
<td>35272</td>
<td>73280</td>
<td>388939</td>
</tr>
<tr>
<td>1992</td>
<td>138050</td>
<td>101316</td>
<td>136468</td>
<td>42229</td>
<td>78816</td>
<td>496879</td>
</tr>
<tr>
<td>1993</td>
<td>135422</td>
<td>89231</td>
<td>160829</td>
<td>44643</td>
<td>81363</td>
<td>511488</td>
</tr>
<tr>
<td>1994</td>
<td>146508</td>
<td>92401</td>
<td>190694</td>
<td>45533</td>
<td>91719</td>
<td>568555</td>
</tr>
<tr>
<td>1995</td>
<td>173384</td>
<td>79011</td>
<td>204724</td>
<td>45706</td>
<td>90743</td>
<td>593568</td>
</tr>
<tr>
<td>1996</td>
<td>184872</td>
<td>65292</td>
<td>213304</td>
<td>50269</td>
<td>92561</td>
<td>606298</td>
</tr>
<tr>
<td>1997</td>
<td>229676</td>
<td>66715</td>
<td>210903</td>
<td>71268</td>
<td>94443</td>
<td>673005</td>
</tr>
<tr>
<td>1998</td>
<td>253186</td>
<td>69545</td>
<td>230745</td>
<td>96551</td>
<td>107390</td>
<td>757417</td>
</tr>
<tr>
<td>1999</td>
<td>232283</td>
<td>64871</td>
<td>217815</td>
<td>104055</td>
<td>114911</td>
<td>733935</td>
</tr>
<tr>
<td>2000</td>
<td>248003</td>
<td>64538</td>
<td>207391</td>
<td>105510</td>
<td>108332</td>
<td>733774</td>
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</table>

PMV and LCV Sales in units (AAI, 2009)
<table>
<thead>
<tr>
<th>Year</th>
<th>Compact</th>
<th>Medium</th>
<th>Large</th>
<th>SUV</th>
<th>LCV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991</td>
<td>38.94%</td>
<td>2.60%</td>
<td>30.55%</td>
<td>9.07%</td>
<td>18.84%</td>
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<tr>
<td>1992</td>
<td>27.78%</td>
<td>20.39%</td>
<td>27.47%</td>
<td>8.50%</td>
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<td>1993</td>
<td>26.48%</td>
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<td>8.73%</td>
<td>15.91%</td>
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<tr>
<td>1994</td>
<td>25.85%</td>
<td>16.30%</td>
<td>33.64%</td>
<td>8.03%</td>
<td>16.18%</td>
</tr>
<tr>
<td>1995</td>
<td>29.21%</td>
<td>13.31%</td>
<td>34.49%</td>
<td>7.70%</td>
<td>15.29%</td>
</tr>
<tr>
<td>1996</td>
<td>30.49%</td>
<td>10.77%</td>
<td>35.18%</td>
<td>8.29%</td>
<td>15.27%</td>
</tr>
<tr>
<td>1997</td>
<td>34.13%</td>
<td>9.91%</td>
<td>31.34%</td>
<td>10.59%</td>
<td>14.03%</td>
</tr>
<tr>
<td>1998</td>
<td>33.43%</td>
<td>9.18%</td>
<td>30.46%</td>
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<td>14.18%</td>
</tr>
<tr>
<td>1999</td>
<td>31.65%</td>
<td>8.84%</td>
<td>29.68%</td>
<td>14.18%</td>
<td>15.66%</td>
</tr>
<tr>
<td>2000</td>
<td>33.80%</td>
<td>8.80%</td>
<td>28.26%</td>
<td>14.38%</td>
<td>14.76%</td>
</tr>
<tr>
<td>Mean</td>
<td>31.18%</td>
<td>11.75%</td>
<td>31.25%</td>
<td>10.22%</td>
<td>15.60%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Make / Model ('95)</th>
<th>Holden Barina</th>
<th>Toyota Camry</th>
<th>Holden Commodore VR</th>
<th>Mitsubishi Pajero</th>
<th>Toyota HiAce</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (tonnes)</td>
<td>0.89</td>
<td>1.33</td>
<td>1.34</td>
<td>2.13</td>
<td>1.45</td>
</tr>
<tr>
<td>Source (eurodb, 2012)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean Weight</td>
<td></td>
<td></td>
<td>1.30</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix C

Interview Questions

This appendix lists the questions asked at the semi-structured stakeholder interviews.

**Industry/Business challenges questions:**

1. What challenges is the parts recycling industry facing today as a whole?
2. As a business owner/operator what challenges is your business facing?

**Business information questions:**

3. Thinking about your business, how long have you been in operation for?
4. What associations is your business a member of? [Probe for accreditations, annual costs involved]
5. What is the size of your workforce? [Prompt for growth/decay]
6. What is the area size of the premises? [Prompt for growth/decay, whether they moved from somewhere else, or whether parts/materials are stored somewhere else]
7. What are the days and hours of operation? [Prompt for overtime work]
8. Do you specialise in any specific brands/models? [Prompt for brands/models, reasons for this specialisation, ongoing/recent, reasons for changes]

**Affordability of new vehicles and hybrids questions:**
9. Thinking about the affordability of new vehicles, what challenges is your business facing as a result of the rising affordability? [Prompt for grey imports]

10. In what ways do hybrids affect your business? [Prompt for LPG/Diesel/other]

**Business operation questions (sourcing):**

11. Now focusing on the operations of your business, how many vehicles/tons of materials/carts of parts does your business handle a year? [Prompt for data collection, type of data, how long its kept, to whom is it reported, and if its accessible]

12. Where are vehicles/parts/materials sourced from? [Probe for frequency of sourcing; Classify sources by volume, cost; explain/give example for each sourcing process and logistics involved]

13. What factors are considered when sourcing vehicles/parts/materials? [Probe for location, condition, price, value/potential revenue]

14. What guidelines or processes do you follow to handle the incoming goods?

**Business operation questions (dismantling):**

15. Are dismantled parts/materials labelled?

16. What factors do you consider when deciding on whether a part is fit for resale/recycling?

17. What is your standard operating procedure when dealing with hazardous waste? [Probe for council directives/guidelines that are followed]

**Business operation questions (output):**

18. Now thinking about your clients, what are the types of customers that buy goods from you? (public/other wreckers etc.) [Probe for long term clients, percentage of revenue coming from long term clients,

19. Do you have clients in the export market? [Probe on demand for export how it has changed in the past 10 years, destination countries, exports share in revenues]
20. What ICT mechanisms do you use to facilitate your operation?

Industry/Business outlook questions:

21. Where do you see the industry in 10 years? How about your business?

22. Scenario questions (In what way your business will it be affected if there was new policy requiring): forced depollution, reporting, zero dollar take back, incentives for disposal of vehicles offered, change in vehicle composition/weight.
Appendix D

Interview Data Analysis Grid

This appendix elucidates the qualitative data analysis of the stakeholder interview data to identify the variables and the causal relationships. The analysis is grouped by area of inquiry (presented in separate sections/tables) and themes (as rows within the tables):

- Business Characteristics: years in business, industry connections, premises area size, specialisation, workforce, turnover, business hours.
- Business Input: factors for sourcing ELVs, sources of ELVs.
- Business Operations: handling of incoming ELVs, handling of hazardous waste, factors for deciding on parts suitability for resale/recycling, stock labelling, use of ICT.
- Business Output: type of customers / revenue streams, export streams.
### D.1 Business Characteristics

<table>
<thead>
<tr>
<th>Theme</th>
<th>Observations</th>
<th>Significance</th>
<th>Relevance</th>
<th>Emerging Theory</th>
<th>Missing Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Years in Business</td>
<td>30 (UPI) + 30 (SS) + 30 (LS) + 20 (SP) + 20 (SP) + 12 (SP) + 18 (UPI) + 2 (SP), or 162 years in combined experience. Interviewed automotive recyclers have been in business for 20 years on average. They have well established businesses with strong commercial presence and links with providers and customers. They are generally proud of their line of work and are constantly on the lookout for ways to improve things. Most perceive their work as doing good for the people and the environment by being the essential link in recycling parts and materials.</td>
<td>To consider, how will the industry has long been given a bad reputation for its less than desired practice. Practice and perception is changing, however, to the better.</td>
<td>Automotive recyclers with strong supplier/customer links are more likely to stay in business for longer.</td>
<td>A survey of operators’ years in business Australia wide (in percentages and turnover).</td>
<td>- Business Age (years) - Business Profits ($/time) - Business Links (int) - Business Survival - Business Age (+) → Business Survival (Likelihood of Staying in Business) (%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variables and Units</th>
<th>Causal Links</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Business Links (+) → Business Age (+) → Business Survival (Likelihood of Staying in Business (%)</td>
</tr>
</tbody>
</table>
## Industry Connections

Auto recyclers can be classified as either - Member of an industry association or more. - Not a member of an industry association. Only 1 out of 8 interviewees is not a member of an industry association. All others are members of at least an association. All of the 7 are members of their state’s automotive/motor trade association. One participant expressed his dissatisfaction with the industry association he is member of, in terms of lack of campaigning against illegitimate operators. Another one sees the association meetings as an opportunity to voice concerns or to propose ideas that could be beneficial to all. Despite the lack of a public policy in this domain, all associations have guidelines (though non-standard) for auto recyclers that promote environment-friendly practice.

Membership of an industry association is not compulsory by law. There is a significant number of operators that are not members of an association. Those who are members link non-members to illegitimate practice. There is no common standard code of practice for auto dismantlers despite earlier attempts to implement one (APRAA).

<table>
<thead>
<tr>
<th>Theme</th>
<th>Observations</th>
<th>Significance</th>
<th>Relevance</th>
<th>Emerging Theory</th>
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<th>Variables and Units</th>
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<td>Professional accredita-tion/membership is often associated with best practice/legitimate operations. We see that the association works both ways: - as a gateway for operators to address common concerns, - as a platform for associations to assist operators in adopting a standard ‘best practice’.</td>
<td>Membership is not to be confounded with licensing from an authority. Those are two different things. How can consensus be reached among operators (both members and non-members) on the kind of problems facing the industry? How do members view the non-members? and vice-versa?</td>
<td>Automotive recyclers that are active members of an industry association are more likely to care for the environment, and stay in business for longer. Membership, however, is not a condition of business longevity.</td>
<td>Historic association membership data (by each state).</td>
<td>Automotive Recyclers belonging to an Industry Association (-) \rightarrow Illegitimate Practice</td>
<td>Automotive Recyclers belonging to an Industry Association (+) \rightarrow Industry Reputation Illegitimate Practice (-) \rightarrow Industry Reputation Environment Friendly Practice (+) \rightarrow Industry Reputation Illegitimate Practice (+) \rightarrow Environmental Damage Industry Reputation (+) \rightarrow Recyclers Joining an Industry Association Recyclers Joining an Industry Association (+) \rightarrow Automotive Industry Association</td>
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<td>Theme</td>
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<td>Premises</td>
<td>Premises Size: 2x16000 (UPI) + 3000 (SS) + 10000 (LS) + 18210 (SP) + 2x4000(SP) + 20230 (SP) + 42000+13000 (UPI) + 3x1500 (SP) Premises Count: 2 (UPI) + 1(SS) + 1 (LS) + 1(SP) + 2(SP) + 1(SP) + 2(UPI) + 3 (SP) An operator can have: -1 site -2 or more sites On average, area size of each business is about 16500sqm Dismantlers in general operate out of large premises. This is due to the stocking system used and the dimensions of the car. In terms of growth Half of the interviewees indicated that they expanded their premises by getting another block of land, whether nearby or in a different area. This is attributed to the need to stock up on cars that are in demand which requires the extra space. One interviewee indicated that they shrank their premises because they figured that by leasing or selling part of their large block they could revenue more than by using it as a stock yard for vehicles.</td>
<td>Initially we thought land size/cost could be a factor that drives the dismantling business. The interviews indicate that it is not only a factor, but also it’s a variable which influences and is influenced by profits/revenue.</td>
<td>Identification of a causal link between land size/cost with business decisions.</td>
<td>Automotive recycling is a space demanding operation. A survey of recyclers to deduce space efficiency metric (turnover/sqm per year). This could also help in the study of the link between sustainability of automotive recycling, with efficiency of operations within space constraints.</td>
<td></td>
<td>- Premises Area Size (sqm)</td>
<td>Premises Area Size (+)→ Premises Costs Premises Costs (-)→ Business Profits Premises Costs (+)→ Operations Optimisation Premises Efficiency (-)→ Premises Area Size Business Profits (+)→ Premises Area Size</td>
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APPENDIX D. INTERVIEW DATA ANALYSIS GRID
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<tr>
<td>In terms of cost one interviewee indicated that they adopted an</td>
<td>efficient process to dismantle vehicles without requiring large blocks of land to stock them. They keep a small inventory of most sought after parts. Their expansion into different locations was merely to strategically cover the metropolitan area. Another interviewee that has a large premises that they use to stock up, but because they aligned their business with an insurance company, they adopted an efficient technique to dismantle vehicles (taking the most sought after parts). While cost of land was found to be a main cost factor among interviewees (in the case of owner-occupier land tax, in the case of lessee rental costs), it was only of concern when the land is either nearing its full capacity, or when they had large areas left unused. The effect can be summarised as: - Expansion (increasing potential revenue) - Reduction (reducing running costs) - Adoption of efficient dismantling / stocking techniques.</td>
<td>Size of land that operators use is not static, it varies with time. In some cases it results in expansion, others reduction, others seek alternative methods to overcome land size limitations.</td>
<td>-</td>
<td></td>
<td>Expand, Shrink, or Relocate. Practice: Restructure, Invest in ICT, Invest in Marketing, Workforce: Grow, Reduce, Retrain</td>
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<td>Specialisation</td>
<td>Auto dismantlers can be classified as having either no specialisation (3) accepting all ELV (make/models/years) or having specialisation (5). The specialisation can be split into: - Brand country/ies (Japanese, European, etc.) - Vehicle type (Passenger, 4WD/Commercial, Other) - Vehicle age (Less than 10 years, 10-15 years, more than 15 years) - Make (Holden, Ford, BMW, combination of makes) - Model (Commodore, Laser, combination of models) Reasons for specialisation in niche markets - Strong demand for used parts (new parts are too expensive) - Advantages of having little competition (1 or 2 competitors in the European car parts market) - Know-how or technical knowledge and skills available (Head mechanic/dismantler with long experience in 4WD) - Strategic cooperation with other dismantlers in the area (one focusing on less than 10 year old vehicles, the other focusing on older) - Strategic cooperation with insurance industry (guaranteed supply of specific makes/models and guaranteed demand for specific makes/models)</td>
<td>As specialised dismantlers operate in niche markets with higher revenue and profit. Unlike non-specialised operators, they do not need economies of scale or large premises to sustain business for long time.</td>
<td>Identification of a causal link between land size/cost with business decisions. Those able to adapt their premises to changes are more likely to stay longer in business.</td>
<td>Breakdown of operators by specialisation (High Margin Low Volume) - Non-specialised (Low Margin High Volume) - Specialisation (by Australia wide)</td>
<td>- Specialisation margins as a result of higher cost base (high cost of land tax or rent) and lower return (low value of scrap metal/parts).</td>
<td>- Causal Links</td>
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### Theme: Workforce

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<tr>
<td>Workforce Size: 25(UPI) + 4(SS) + 20(LS) + 13(SP) + 10(SP) + 11(UPI) + 15(SP)</td>
<td>The aim of this question is to collect raw workforce data about businesses and to better understand the underlying mental models that drive this factor and in what ways. We found that auto recyclers control their workforce size and skill level depending on their financial situation (e.g. business is growing) and their drive to find that auto recyclers control their workforce size and skill.</td>
<td>As long as niche markets of automotive recyclers to continue to exist, the potential for historical Labour (int) - Unskilled to thrive in their workforce efficiency or productivity is high.</td>
<td>A wider survey of automotive recyclers to study the link between workforce size and business turnover, operations optimisation, and skilled/unskilled labour.</td>
<td>- Workforce Size (+)→ Labour Cost</td>
<td>- Labour Cost (-)→ Business Profits</td>
<td>- Labour Cost (+)→ Operations Optimisation</td>
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- **Workforce Size**
  - Static (1 only had business for 2 years)
  - Growing (3)
  - Shrinking (2)
  - Fluctuating (2)

- **Improve Skill Level**
  - Hire skilled workers (1)
  - Train/retrain current workers (2)

- **Causes for Changes**
  - Work laws
  - Knowing the employee for too long
  - Knowledgeable employees are key asset
  - Business growth resulting from strong demand
  - Cost reduction due to market slow down

- **Finding ways to be more efficient**
  - Non-suitable/unskilled labour (3)
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<td>The reason given by one of the respondents for not reducing the workforce size: difficult to dismiss someone for having known them for a long time was something we did not expect to emerge. We had expected that finding skilled labour “Hire Skilled Workers” to be a common issue, which we found the most pronounced (3 out of 8). Dealing with a dismissal for whatever reason (economic, skills) is something that affects all types of small business and is not unique to this industry. Labour Cost Labour cost varies depending on the function of the employee. Skilled mechanics and salespeople are well paid and represent a major cost factor as well as an asset / investment for the business.</td>
<td>increase efficiency (achieve higher turnover with same workforce size, or maintain turnover while reducing workforce size)</td>
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<td>Turnover</td>
<td>Only 2 participants shared a number of their annual turnover in terms of Dollars (2.4M and 2.3M Dollars).</td>
<td>To gather data about the</td>
<td>Identification</td>
<td>Non-</td>
<td>Financial data - Business</td>
<td>ELVs Bought (+)→ ELVs in Yard</td>
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<td>With others the focus was on the number of cars handled a year.</td>
<td>of several causal links</td>
<td>specialised</td>
<td>for dismantlers</td>
<td>Turnover (8) - ELV Turnover</td>
<td>ELVs in Stock (-)→Available Yard Space</td>
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<td>Number of cars handled annually (could be) 3000 (up to 6000) + 0 &lt;full capacity&gt; + 1000 + 168 + 1300 (260-sp only) + 250 + 7200 + 1250 (UPI) + (LS) + (SP) + (SP) + (UPI) + (SP)</td>
<td>to show their</td>
<td>turnover/revenue</td>
<td>(units per year)</td>
<td>Scrap Metal Price (+)→ ELVs Disposed</td>
<td>Available Yard Space (+)→ ELVs Bought</td>
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<td>On average, turnover is 1520 ELVs a year.</td>
<td>between 1000 + 168 + 1300 (260-sp only) + 250 + 7200 + 1250 (UPI) + (LS) + (SP) + (SP) + (UPI) + (SP)</td>
<td>require economies of</td>
<td>over the past (Inverse of ELV)</td>
<td>ELVs Disposed (-)→ ELVs in Yard</td>
<td>ELVs Bought</td>
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<td>Currently in the yard (for only 6 out 8): 400 + 120 + 500 + 50 + 400 + 200 + 1650 + 0</td>
<td>recycers. The size/cost/skill</td>
<td>scale and need</td>
<td>Occupancy - weeks in the yard</td>
<td>Parts Dismantled (+)→ Parts on Shelf</td>
<td>Parts on Shelf (-)→ Available Shelf Space</td>
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<td>On average, ELVs in the yard about 420.</td>
<td>turnover has level and</td>
<td>to have</td>
<td>Yard Capacity (sqm) - Available Yard Space (+)</td>
<td>Parts Dismantled</td>
<td>Available Shelf Space (+)→ Parts Dismantled</td>
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<td>In terms of trend, turnover can be:</td>
<td>been increasing, business efficient</td>
<td>partly due to profits practice.</td>
<td>- ELVs in Yard (units) - ELVs (Bought (units) - ELVs Disposed)</td>
<td>Demand for Used Parts (+)→ Parts Sold</td>
<td>Parts Sold (-)→ Parts on Shelf</td>
<td></td>
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<td></td>
<td>- Static (2)</td>
<td>adopting new software (3)</td>
<td>ELVs Bought (+)→ ELVs in Yard</td>
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<td></td>
<td>- Increasing (5)</td>
<td>adopting new marketing/sale channels (2)</td>
<td>ELVs in Stock (-)→Available Yard Space</td>
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<td>- Decreasing (0)</td>
<td>Full yard capacity with weak demand for parts and scrap steel price too low - Yard capacity under-utilised</td>
<td>ELVs in Stock (-)→Available Yard Space (+)→ ELVs Bought</td>
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<td></td>
<td>- Fluctuating (1)</td>
<td>- Managing cash flow (1)</td>
<td>ELVs Bought (+)→ ELVs in Yard</td>
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<td>Causes for changes in turnover:</td>
<td>'IBISWorld' risk report indicates that the industry's lifecycle is in decline (stagnant growth) which contradicts with this observation - Increasing turnover</td>
<td>ELVs Bought (+)→ ELVs in Yard</td>
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<td></td>
<td>- Adopting new ICT software (3)</td>
<td>/profits</td>
<td>ELVs Disposed (units) - Yard</td>
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<td>- Adopting new marketing/sale channels (2)</td>
<td>allows them to better estimate</td>
<td>Capacity (sqm) - Available Yard</td>
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<td></td>
<td>- Full yard capacity with weak demand for parts and scrap steel price too low - Yard capacity under-utilised</td>
<td>the value of an ELV based on potential revenue</td>
<td>Scrap Metal Price ($/tonne) - Parts Turnover (units per year) - Parts Dismantled (units) - Parts on Shelf (units) - Demand for Used Parts - Parts Storage</td>
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<td></td>
<td>- Managing cash flow (1)</td>
<td>from parts sales.</td>
<td>Used Parts Sold (units) - Demand for Used Parts - Parts Storage</td>
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### Theme: Business Hours

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<tr>
<td>Auto dismantlers operate 9 to 5. They recognise that overtime work is costly and generally try to avoid it. Operators that engage in mechanical repairs activity are the ones more likely to have overtime. The one exception is the you-pull-it type yards that operate 7 days a week to cater for the working DIY.</td>
<td>Dismantlers that rely on another revenue stream such as mechanical repairs recognise its profit potential and hence are able to afford the costs of overtime work. Revenue from parts / materials trade alone cannot justify the cost overtime work.</td>
<td>Labour cost from overtime can be ignored in a costing model.</td>
<td>Automotive recycling is a thriving industry operating with spare capacity. Dismantling activity is a costly process. Operators are constantly trying to minimise it.</td>
<td>Man-hours spent per ELV (including sourcing, dismantling, stocking, selling, disposing).</td>
<td>- Weekly Business Hours - (Workforce Size x Weekly Business Hours)</td>
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### D.2 Business Input

#### Theme | Observations | Significance | Relevance | Emerging Theory | Missing Data | Variables and Units | Causal Links
--- | --- | --- | --- | --- | --- | --- | ---
Factors for sourcing ELVs | Auto recyclers consider the following factors when sourcing vehicles: Vehicle-related factors: - Mechanical condition (X Engine/transmission/transfer box etc.) - Location (X - determines time to get it into stock + cost of towing) - Legitimacy of source/seller (legal requirement) - Cost of purchase X (includes towing cost) - Value as scrap (worst case scenario for some dismantlers) - Cost of towing - Parts present/missing (Inherent value, potential revenue) - Current stock level - Current demand sales in the past year for parts Business-related factors: - Current cashflow - Available yard/shelf space | Cost of vehicle purchases is the largest cost component in running an auto recycling business. By focusing on optimising this cost and associated factors, the profitability and business longevity is most affected. | Uncovering the factors that influence vehicle purchase decisions is important because we are modelling the demand for ELVs at a business level. | Uncovering the factors that influence process which is an involved weighting of variables. | ELV Cost of Purchase | ELV Cost of Purchase

3 out 8 Interviewed recyclers rely on software to help them decide on a purchase. This is encouraging other recyclers to take on a similar approach. | ELVs Bought ELV | ELV Cost of Purchase | ELV Cost of Purchase

| Variables and Units | Causal Links
--- | ---
ELV Cost of Purchase | (-)→ Business Profits
ELV Cost of Purchase | (-)→ ELVs Bought ELV
ELV Cost of Purchase | (-)→ ELV's Bought ELV
ELV's Bought ELV | Parts (+)→ ELVs Bought ELV
ELV Cost of Towing | ELV Cost of Towing (-)→ Business Profits
ELV Value as Parts | Business Profits ELV Age
ELV Value as Parts | (-)→ ELV Value as Parts
ELV Value as Parts | ELV Age (+)→ ELV
ELV Value as Scrap | Value as Scrap ELV
ELV Value as Scrap | Damage (-)→ ELV Value as Parts
ELV Value as Scrap | ELVs Bought ELV
Purchased Scrap Metal | Scrap ELV Value as Scrap
Price (+)→ ELV Value as Scrap | (+)→ ELVs Bought ELV

---

**Note:** The table above summarizes the factors and their significance in the context of vehicle sourcing and business profitability in the auto recycling industry. The factors include cost-related, location, legitimacy, and operational considerations. The table also highlights the importance of using software in decision-making and the impact on profitability and business longevity.
APPENDIX D. INTERVIEW DATA ANALYSIS GRID

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| Sources of ELVS | Auto recyclers source vehicles from: - Direct from the public (5) - Local councils (1) - Car dealerships (1) - Towing companies (2) - Salvaged car auctions (7) - Crash repairers (3) - Insurance companies (1) - Overseas sources (imports) (1)  
When prompted, a participant explained the rationale behind aligning with insurance and crash repairers: It was the drive to improve the business by being able to access stocks of ELVs direct from the insurance company (bypassing the added costs by speculation at salvaged auctions, hence reducing their purchase cost) and being able to meet the crash repairers' demand for specific parts the moment a car goes to repair.  
This alignment allowed them to locate cheaper feedstock ELVs without having to go to the auctions (Less cost of purchase). It also previously unknown was the primary sources of ELVs for auto dismantlers. By uncovering the major incoming flows we're able to determine the factors that control them and hence that have leverage on auto dismantlers. Such as the public and crash repairers, depending on their operations. They rely on other sources, such as the insurance agreement with insurance companies supplier agreements with insurance companies.  
| Previously unknown was the major sources of ELVs for auto dismantlers. | By uncovering the major sources of ELVs for auto dismantlers. | Auto dismantlers of ELV | Breakdown | | | Bidders at Salvaged Car Auctions (+)→ ELVs Price at Auctions  
Recyclers Sourcing ELVs Direct (-)→ Salvage Stock Sent to Auctions  
Written-Off Vehicles By Insurance (+)→ Salvage Stock Sent to Auctions  
Salvage Stock Sent to Auctions (+)→ Auction Houses Turnover  
Auction Houses Turnover  
(+)-→ Bidders at Salvaged Car Auctions  
Car Auctions |
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<td>ELVs from Public</td>
<td>on their nature of their business (U-Pull-It).</td>
<td>There is also an emerging stream, from insurance companies direct to auto dismantlers, bypassing auction houses.</td>
<td></td>
<td></td>
<td>ELVs from Public Recyclers Sourcing ELVs from Insurance Recyclers Sourcing ELVs from Japan AUD/JPY Exchange (int) ELVs Imported from Japan (units)</td>
<td>Bidders at Salvaged Car Auctions (+)→Auction Houses Turnover *Supplier Agreement with Crash Repairers (+)→ Demand for Used Parts *Operations Optimisation (+)→ Supplier Agreement with Crash Repairers *Operations Optimisation (+)→ Customer Agreement with Insurance Companies *Marketing Expenditure (+)→ ELVs Offered by the Public *ELVs Offered by the Public (-)→ Demand for ELVs Promoting Salvage Removal to Public JPY/AUD Exchange (+)→ ELVs Bought from Japan</td>
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## D.3 Business Operations

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<tbody>
<tr>
<td>Handling of ELVs</td>
<td>All auto recyclers follow a well-defined process upon receiving an ELV. The process include several steps: 1- Allocating a number to the vehicle (entering details 2- Testing/checking for good parts (visual inspection, starting engine/test driving if possible) 3- Depollution (where needed/possible: includes drainage of fluids, A/C gas, fuels, removal of batteries, tyres/wheels and exhaust systems -catalytic converters) 4a- Moving vehicle to yard (if U-Pull-It type) 4b- Dismantling vehicle as needed (by the public if U-Pull-It type) 5- Labelling dismantled parts 6- Stocking dismantled parts on shelves 7- Moving vehicle to disposal/holding yard until it is disposed of.</td>
<td>To understand ELVs are the feedstock for auto dismantlers</td>
<td>Auto mans-hours</td>
<td>Work</td>
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To understand how ELVs are handled by dismantlers. ELVs are the feedstock for auto dismantlers. Once dismantled, ELVs are split into various processes in parts that go ELV. Workman-hours spent on each step by business type.
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<tr>
<td>Handling</td>
<td>All auto dismantlers follow a well-defined process for dealing with hazardous waste. - Fuel: Whether it's petrol or diesel is extracted from vehicles and collected for reuse by staff. One of the interviewed dismantlers collects LPG and re-uses it in forklifts. - Engine oil, brake fluid, coolant, transmission fluid: Drained and collected in a large tank for collection by oil recyclers. - A/C gas: is extracted for re-use/re-sale. - Tyres: Some tyres are put for sale as used tyres. Tyre recyclers charge a premium (2-10 dollars) for collecting tyres, so auto dismantlers minimise this cost by placing 4 tyres into each ELV shell which is collected by scrap steel recyclers (who allow this). - Catalytic converters: Collected and sold to scrap steel recyclers at a premium. - Batteries: Collected and sold in pallets to scrap steel recyclers. 2 of the interviewed dismantlers resell used batteries that test good.</td>
<td>To understand how these materials are handled due to their environmental impact.</td>
<td>Auto hazardous materials by weight, value</td>
<td>Most generated by and recycling type.</td>
<td>Breakdown of recovered fuel (litres) - scrap metal content (tonnes) - recovered A/C gas (litres) - recovered fluids (litres) - recycled batteries (units) - available fluids storage space (litres) - available waste storage space (sqm) - disposed AC gas (litres) - disposed fluids (litres)</td>
<td>Recovered X (→)</td>
<td>Available X Storage Space</td>
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<td>Hazardous Waste</td>
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To understand how these materials are handled due to their environmental impact.
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<th>Variables and Units</th>
<th>Causal Links</th>
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| - Disposed Catalytic Convertors (units) - Disposed Fuel (litres) *Disposal of recovered materials/parts is used a loose term here and may refer to selling (either to the public or a 2nd tier recycler at a revenue), disposing (to a 2nd tier recycler at a cost), or re-using (within the business—such as fuel, tyres)
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<tr>
<td>Factors for deciding on parts suitability for resale/recycling</td>
<td>Auto recyclers consider the following factors when deciding on whether a part is fit for recycling (worth the effort to dismantle): Part-related factors: - Mechanical condition (4) - Physical condition (for non-mechanical parts i.e. Panels) (4) - Mileage (2) - Potential revenue (1) - Observation - Current demand (1) - Current stock (1) Business-related factors: - Not applicable (customer determines that) (2) - Not applicable (dismantles everything) (1)</td>
<td>Parts</td>
<td>Dismantling</td>
<td>Dismantling</td>
<td>- Labour Cost for</td>
<td>- Labour Cost for</td>
<td>ELV Mileage (-)→ ELV Value</td>
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<td>The dismantling process is major and time consuming. Some recyclers have chosen to leave it for the customer; others have adopted intelligent systems to help them only dismantle what's in demand. Low in stock and revenues the most.</td>
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<td>Dismantling costing data for ELVs is an involved process which type (could be major) process which is dependent on business and work. Used Part Value is (8) - New Part. New Part Value (+)→ Used Part Value Used.</td>
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<td></td>
<td>Cost for Part Removal (1) - Labour Cost for Part Life Remaining (3) - ELV Mileage (km) - Cost Part Life Remaining (3) - Dismantled Parts - Dismantled (+)→ Labour - Cost Part Life Remaining (3) - +→ Used Part Value</td>
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<td>Stock Labelling</td>
<td>Labelling is done to help in stock control and in record keeping to identify source of used parts. It includes: - Vehicle labelling (6). - Dismantled parts labelling (5). Large scale-you pull it type operators do not label their parts as it is logistically difficult to do so and their business model relies on the customer dismantling the parts themselves.</td>
<td>Because we need to identify how common this activity is and its importance from a business operations perspective.</td>
<td>Parts labelling is a labour intensive business that can help in increasing vehicle/parts efficiency.</td>
<td>A wider survey of auto businesses are less likely to engage in specifics about labelling.</td>
<td>- ELV Labelling (%) - Parts Labelling (+)→ Labour Cost</td>
<td>- ELV Labelling (%) - Labour Cost</td>
<td>Parts Labelling (+)→ Labour Cost</td>
</tr>
<tr>
<td>Use of ICT</td>
<td>Auto dismantlers responded the following when asked about their ICT systems: - None (1) - Pinnacle (3) - Armas (1) - Aden (1) - Own software (In house developed) (2) Most software is connected with other suppliers and provides real time stock data. One dismantler links up with an insurance company’s claim database to foresee supply and demand. The dismantlers that run the proprietary software share their current stock of cars online. Most operators said that after implementing a stock management software, revenue increased dramatically. In one case by as much as 50% over 2 years.</td>
<td>Importance of ICT in auto dismantling. To understand if use ICT could influence the profitability and longevity of a business.</td>
<td>The reliance of auto dismantlers in Australia on ICT to help manage their stock.</td>
<td>Revenue figures between 2 populations (one with software, one without).</td>
<td>- Cost of ICT ($) (time) - Business Reliance (+)→ Business Reliance on ICT (% of budget or turnover spent annually on ICT)</td>
<td>Operations Optimisation (+)→ Business Reliance on ICT Business Reliance Profits</td>
<td>Operations Optimisation (+)→ Business Reliance on ICT Profits</td>
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## D.4 Business Output

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<th>Theme</th>
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<th>Causal Links</th>
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<tr>
<td>Type of Customers</td>
<td>Revenue by type of clients (Type of business*) - Trade: NC(UPI) + 0%(SS) + 90%(LS) + 70%(SP) + 80%(SP) + 90%(SP) + 15%(UPI) + 40%(SP) - Retail Market: NC (UPI) + 100%(SS) + 10%(LS) + 30%(SP) + 20%(SP) + 10%(SP) + 85%(UPI) + 60%(SP) * UPI: U-Pull-It, SM: Small Scale, LV: Large Scale, SP: Specialised - One of the respondents said they’re not sure who they cater for exactly as they do not collect this sort of information. - 3 of the other 7 respondents have at least 60% of their revenue derived from the retail market. (81.67% average) - The remaining 4 respondents revenue from catering to trade market (vehicle repairers/mechanic workshops etc.) that makes up at least 70% of their overall revenue (82.5% average). Long term clients ND(UPI) + ND(SS) + 40%(LS) + ND(SP) + 80%(SP) + 90%(SP) + ND(UPI) + 35% (SP) - Long term clients form a significant part of the clientele base for some operators with a 60% aggregate average of revenue derived from returning clients.</td>
<td>Literature provides little insight into the operations of automotive recyclers: a thriving business activity, but little information on how revenue is created. We focused on this area because we originally wanted to identify where to parts/materials go to. During the first interview it was discovered that business decisions along with the business model strongly influence where to and how parts/materials are disposed. The underlying driver is profit generation. Furthermore, the numbers quoted by the participants masked the dynamics of running a recycling business. Whether it’s a specialised dismantler, a UPI or small recycler, business decisions are</td>
<td>To understand</td>
<td>Automotive</td>
<td>Same data</td>
<td>- Long Term Clients (%)</td>
<td>Refer to</td>
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<td>/ Revenue Streams</td>
<td>Revenue from streams - Mechanical repairs/vehicle servicing: 0% (UPI) + 80%(SS) + 0%(LS) + 30%(SP) + 50%(SP) + 10%(SP) + 0%(UPI) + 7.5% (SP) - Sale of parts: 50% (UPI) + 20%(SS) + 90%(LS) + 70%(SP) + 50%(SP) + 90%(SP) + 50%(UPI) + 92.5% (SP) - Sale of scrap metal: 50% (UPI) + 0%(SS) + 10%(LS) + Neg%(SP) + Neg%(SP) + Neg%(SP) + Neg%(SP) + Neg%(SP) + Neg%(SP) + Neg%(SP)</td>
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Refer to Turnover
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<th>Variables and Units</th>
<th>Causal Links</th>
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<td></td>
<td>Mechanical repairs/vehicle servicing is a major revenue stream for small recyclers as sale of parts of parts activity is less frequent. Specialised recyclers rely on mechanical repairs and/or servicing to complement their used parts trade despite acknowledging that it is not as profitable as pure used parts trade as it requires higher wages for the highly skilled labour/expertise. The UPI group of recyclers try to balance revenue from sale of used parts and from sale of ELVs as scrap as these ELVs are generally of low yield, and keeping the vehicles for too long jeopardises their potential to turnover stock. Revenue from sale of scrap metal is most significant in the case of UPI-group as they have the economy of scale on their side. For smaller operators it is only a small form of revenue used to cover the overhead costs associated with ELV purchase/transport/stocking.</td>
<td>made daily on how to dispose of stock in the most profitable way. When prices of scrap metal go up, revenue is made from selling the hulls stocked in the yard for a long time. When demand for a particular part arises that has been sitting on the shelf for several months, every effort is made to dispose of it. Also discovered that recurring clients were essential to sustained revenue. Other businesses in the industry rely on auto dismantlers as suppliers of quality used parts. The reliance is cyclic and essential controlling loop in the industry.</td>
<td>The system has a significant reliance on long term clientele / business networks as they drive demand for both services and parts.</td>
<td>- Business Revenue from Sale of Scrap Metal ($/time) - Disposal Cost of Tyres ($/time) *Scarp Metal includes batteries</td>
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Export streams

Responses can be summarised as follows: - Done export in the past (1) - Nigeria, Malaysia - Yes (2) - France (2), Middle East(1), UK(1) - Will consider exports in the future (1) - No (4) One of the respondents views that the export of old vehicles/parts is a threat to the industry and to the environment because it’s often done illegally and without due care to pollutants. Another respondent views export of used parts as a proud activity because they export Australian made parts to parts of the world where it’s difficult to get them. Two respondents from different localities pointed out that they know of others who export vehicles and/or parts to countries in Africa. Another respondent remarked that demand for export is focused on older vehicles whereas local demand is for newer models.

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<th>Theme</th>
<th>Observations</th>
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<tr>
<td>Export</td>
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<td>Extent of export of ELVs and used car parts in Australia.</td>
<td>Export of</td>
<td>Illegal or</td>
<td>Historic</td>
<td>- Exported</td>
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<td>ELVs and used</td>
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<td>figures for ELVs</td>
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<td>export of</td>
<td>minor flow</td>
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<td>cost of ELVs</td>
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<td>ELVs and used</td>
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<td>car parts</td>
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<td>figures.</td>
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<td>dismantlers</td>
<td>environment.</td>
<td>Survey of exporters to</td>
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<td>The flow</td>
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<td>influences the purchase cost</td>
<td>of ELVs. For</td>
<td>extent of depollution</td>
<td>of ELVs and</td>
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<td>legitimate</td>
<td>recycle,</td>
<td>practice of dealing with hazardous waste when</td>
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<td>revenue from used parts</td>
<td>export activity</td>
<td>insignificance</td>
<td>dismantling,</td>
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Exported ELVs (+) De-
## D.5 Views on Vehicle Affordability and Fuel Technologies

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<th>Theme</th>
<th>Observations</th>
<th>Significance</th>
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<tr>
<td>Effects of Affordability of New Vehicles</td>
<td>The question was modified for specialised recyclers to: introduction of lower priced/more affordable models/makes to the same make/region specialisation. Respondents replied with how their business might be affected (count) [Reasons]: - Bad for business (3) [Encouraging throw away behaviour, cheap cars (both current and newly introduced) thrown away instead of being repaired, service/guarantee by dealer for long periods] - Good for business (4) [Potential demand for more parts, expansion of products range] - No Impact (1) [Specialising in a specific model which has lead new car sales for 10 years up to recently meaning it will be in demand for another 10 years] Grey Imports: - Good for business (3) [Potential demand for more parts] - Not applicable (2) [Specialised in local makes] - Don’t know (1) [Never dealt with them]</td>
<td>Over the past decade, the combination of reduction in tariffs on car imports and new vehicle manufacturers entering the automotive market in Australia has led to the lowering of cost of new vehicles. From a motorist perspective, new vehicles became more affordable, hence more accessible. It also made up keeping old vehicles less desirable as new vehicles come with extended warranties. Because automotive recyclers rely heavily on the demand for used parts from the public, we were interested in understanding how this factor might be affecting the recycling business.</td>
<td>Cars are consumable products that get replaced at an increasing rate. There exists a causality (though a delayed one) between the new vehicles market and the used parts market.</td>
<td>New vehicle affordability has a mixed impact on the automotive recycling industry.</td>
<td>- New Car Pricing ($) - New Car Sales (units/time) - New Makes/Models on the market (int/time) - Grey imports (units) - Used Vehicles on the market (units)</td>
<td>New Car Pricing (-)→ New Car Affordability New Car Affordability (+)→ Sales of New Vehicles New Car Sales (+)→ Old Vehicles on the market New Car Sales (-)→ Average Vehicle Age New Makes/Models (+)→ Demand for Used Parts Grey Imports (-)→ Demand for Used Parts</td>
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<td>In some cases (recyclers with large volumes) we were establish the negative impacts as there’s more old ELVs on the market but with little demand. On the other hand we were surprised to discover that, particularly for those specialised, it has no impact or a positive one, as the new entrants and new models introduced into the market provided more opportunities both in terms of sourcing of a niche stock and meeting parts demand to a niche market.</td>
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<td>Theme</td>
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| Effects of Emerging Fuel Technologies | - Don’t know (5) [Uncertainty about licensing, safety and technical requirements for hybrids, have not dealt with hybrids yet]  
- Good for business (2) [Diesels in high demand]  
- Not Applicable (1) [Specialise in local makes, does not accept/handle LPG or Diesels] | With the increasing popularity of hybrid/diesel/LPG fuelled vehicles (due to lower running costs and environmental concerns by the public), we wanted to know how this would impact the recyclers business. | There exists a delayed causality between the increase in the proportion of hybrid/diesel/LPG new car sales and the pressure on recyclers to adapt in the long run. | Changes in the automotive technologies | - Hybrids New Car Sales (units) - Diesel New Car Sales (units) - LPG New Car Sales (units) - Special New Car Sales Proportion (%) (Hybrids + Diesels + LPG / New) - Special Cars Proportion (%):within the fleet - Fleet Size (units) | Special New Car Sales Proportion (+)→ Special Cars Operations Optimisation |

Diesel ELVs represent excellent revenue opportunities, particularly for those specialised (in 4WD and German makes). Most business owners view the variety in fuel technologies represent a challenge because it requires special licensing and/or training.
Appendix E

Pre Workshop Survey

This appendix presents the questionnaire distributed to potential participants in the Scenario Planning workshop to help verify the validity of the identified model focus areas and to help qualify the participant background.
Thank you for taking the time to complete this short survey. By answering the following three questions you will help us better plan for the workshop. It will also make the workshop more relevant and interesting for all participants. If you choose to complete it please save this file in its current Word format and email it to ezzat.elhalabi@anu.edu by COB Tuesday 16 October 2012. Your identity and responses will remain confidential. Only aggregate results may be published.

1. The following table summarises six focus areas we believe are of significance to the auto recycling industry in Australia. Please indicate the importance level which you think is appropriate by typing an X in the corresponding cell. Feel free to comment on your choice and to add other areas to the list while indicating their importance level and the reasons why they are of significance.

<table>
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<tr>
<th>Focus Area</th>
<th>Very Important</th>
<th>Important</th>
<th>Fairly Important</th>
<th>Somewhat Important</th>
<th>Not at All Important</th>
<th>Comments</th>
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<td>Sustainability of the auto recycling business and industry</td>
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<td>Supply of end of life vehicles (availability, purchase costs, etc.)</td>
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<td>Demand for used parts (revenue, client base, etc.)</td>
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<td>Premises/land related (rental costs, location, etc.)</td>
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<td>Labour related (work laws, labour costs, etc.)</td>
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<td>Industry image and reputation</td>
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<td>Others/ Additional Comments:</td>
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2. Have you participated in a Scenario Planning workshop before? ( ) Yes, ( ) No

3. Which stakeholder group(s) do you fall into – place an X where applicable?

| Auto Recycler Please indicate the following (where applicable approximate figures, ranges or averages for the last 3 years are fine): |
|-----------------------|-----------------------|-----------------------|-----------------------|
| State(s) in which your business has branches: |
| Number of years in operation: |
| Number of employees: |
| Total area size of all premises (in sqm): |
| Annual turnover: |
| Number of damaged/old vehicles bought per year: |

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<th>Industry association official</th>
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<td>– Please indicate for which state(s):</td>
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( ) Other – please indicate:
Appendix F

Post Workshop Survey

This appendix presents the questionnaire distributed to participants at the end of the Scenario Planning workshop to verify whether perceptions on the problem or model areas have changed and to provide an opportunity for the participant to input further comments on the scenarios and issues.
Thank you for your time and for participating in this workshop. By answering the following four questions you will help us better understand how the workshop went and help us better analyse the results. Your responses will remain confidential. Only aggregate results may be published.

1. We would like to know how your perceptions might have changed. The following table summarises six focus areas we believe are of significance to the auto recycling industry in Australia. Please indicate the importance level which you think is appropriate by placing X in the corresponding cell. Feel free to comment on your choice and to add other areas to the list while indicating their importance level and the reasons why they are of significance.

<table>
<thead>
<tr>
<th>Sustainability of the auto recycling business and industry</th>
<th>Very important</th>
<th>Important</th>
<th>Fairly important</th>
<th>Somewhat important</th>
<th>Not at All important</th>
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<td>Supply of end of life vehicles (availability, purchase costs, etc.)</td>
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<td>Industry image and reputation</td>
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<td>Others/ Additional Comments:</td>
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2. For each area below, comment on other points that you believe are of significance and that were addressed inadequately or deserved more attention during the discussions:

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<thead>
<tr>
<th>Trends</th>
<th>Uncertainties</th>
<th>Scenarios</th>
<th>Strategies</th>
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</thead>
</table>

Ezzat El Halabi – Post Workshop Questionnaire
3. Which stakeholder group(s) do you fall into – place an X where applicable?

- [ ] Auto Recycler
- [ ] Industry association official
- [ ] Other – please indicate

4. Rate the following:

<table>
<thead>
<tr>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neither</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
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<tr>
<td>The main issues affecting the business/industry were addressed appropriately</td>
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Comments:

My understanding of the main issues affecting the industry has changed

Comments:

5. Rate the following:

<table>
<thead>
<tr>
<th>Very Satisfied</th>
<th>Satisfied</th>
<th>Neither</th>
<th>Dissatisfied</th>
<th>Very Dissatisfied</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time allocated to activities</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Comments:

Time allocated to discussions

Comments:

Breadth of topics covered

Comments:

Depth of topics covered

Comments:

Clarity of procedures/activities

Comments:

Your overall experience

Comments:

Others/ Additional Comments:

6. If you were to participate in this workshop again, what would you like to see done differently?

____________________________________________________________________________________________________
____________________________________________________________________________________________________

Thank you once again for your participation
Appendix G

SP Workshop Worksheets

This appendix presents a sample of the worksheets used by the participants during the Scenario Planning workshop.
### First Activity: Identifying and ranking Trends

**Allocated Time:** 20 minutes

<table>
<thead>
<tr>
<th>Areas of Interest</th>
<th>Supply of damaged/old vehicles</th>
<th>Demand for used parts</th>
<th>Premises/Land related</th>
<th>Labour related</th>
<th>Industry image and reputation</th>
</tr>
</thead>
</table>

#### Trends

- **Political**
  - E.g., international trade, relocation policies

- **Economic**
  - E.g., automation, trend towards environmentally friendly vehicles, fuel taxation

- **Social**
  - E.g., younger population, attitudes to work, income distribution

- **Technological**
  - E.g., innovation, new product development

- **Environmental**
  - E.g., global warming, environmental issues

- **Legal**
  - E.g., competition law, health and safety, employment law

---

**First Activity Summary (in pairs):**

1. For each area of interest, brainstorm trends (driving forces) that may impact that area in the next decade. The examples shown are for indicative purposes only. Try to be specific as much as possible.

2. Write each trend in BLOCK LETTERS on a post-it note with a colour of the corresponding impact level. Use PINK for High, YELLOW for Medium, and BLUE for Low impact.

3. Place the note onto the corresponding cell.

4. If the same factor impacts more than one area, re-write it on a new post-it note while adhering to the colour coding. (e.g. a factor may have a high impact on one area, but medium on another. Use pink notes for the first, yellow for the second)

5. Discuss with your partner the reasons behind your choices.

6. Choose with your partner the most important trend or two for each area (place an asterisk * next to it).

7. Discuss with your partner the driving forces behind the chosen trends.
### Areas of Interest

<table>
<thead>
<tr>
<th>Areas of Interest</th>
<th>Supply of damaged/old vehicles</th>
<th>Demand for used parts</th>
<th>Premises/Land related</th>
<th>Labour related</th>
<th>Industry image and reputation</th>
</tr>
</thead>
</table>

#### Uncertainties

- **Political**
  - e.g. international trade, taxation policy

- **Economic**
  - e.g. interest rates, exchange rates, inflation, unemployment, stock market

- **Social**
  - e.g. ageing population, attitudes to work, income distribution

- **Technological**
  - e.g. innovation, new product development

- **Environmental**
  - e.g. global warming, environmental issues

- **Legal**
  - e.g. competition law, health and safety, employment law

### Second Activity: Identifying and Ranking Uncertainties

**Allocated Time:** 20 minutes

1. For each area of interest, brainstorm uncertainties (unpredictable elements) that may impact that area in the next decade. The examples shown are for indicative purposes only. Try to be specific as much as possible.

2. Write each factor in BLOCK LETTERS on a post-it note with a colour of the corresponding uncertainty level. Use **Pink** for High, **Yellow** for Medium, and **Blue** for Low uncertainty.

3. Place the note onto the corresponding cell.

4. If the same uncertainty impacts more than one area, re-write it on a new post-it note while maintaining the colour coding.

5. Discuss with your partner the reasons behind your choices.

6. Choose the most important uncertainty for each area that needs to be brought into the following group discussion.
### Causal Elements or Comments

<table>
<thead>
<tr>
<th>Areas of Interest</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply of damaged/old vehicles</td>
<td></td>
</tr>
<tr>
<td>Demand for used parts</td>
<td></td>
</tr>
<tr>
<td>Premises/Land related</td>
<td></td>
</tr>
<tr>
<td>Labour related</td>
<td></td>
</tr>
<tr>
<td>Industry image and reputation</td>
<td></td>
</tr>
</tbody>
</table>

#### Third Activity Summary (in a group):
1. Discuss and agree on a scenario name. Write the chosen name in the space provided.
2. Discuss the impact that this scenario will have on an area of interest. Estimate a percentage or a range of percentages of change under this scenario and the approximate time frame (e.g., 20% increase in premises rental costs within 2 years, 50%–75% decrease in demand for used parts over 5 years).
3. Write each estimate in BLOCK LETTERS on a YELLOW post-it note and place it onto the corresponding area of impact.
4. Agree on a significant effect or two. Think of why they’re important.
Fourth Activity: Strategies and Policies  
Allocated Time: 20 minutes

Scenario Name: _______________________________________________

<table>
<thead>
<tr>
<th>Business Strategies</th>
<th>Industry Strategies</th>
<th>Policies (External to industry)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario A</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fourth Activity Summary (as a group):

1. Brainstorm for **strategies internal to the business** that you think are best suited and are likely to be followed under this scenario.

2. Write each business strategy in BLOCK LETTERS on a **PINK** post-it note and place it accordingly.

3. Brainstorm for **industry strategies** that you think are best suited and are likely to be followed under this scenario.

4. Write each industry strategy in BLOCK LETTERS on a **YELLOW** post-it note and place it accordingly.

5. Brainstorm for policies **external to the industry** that would or should be adopted under this scenario.

6. Write each policy in BLOCK LETTERS on a **BLUE** post-it note and place it accordingly.

7. Agree on an important business strategy, industry strategy and a policy that could be brought into the following group discussion. Think of why they’re important and in what ways they will impact the business/industry.
Appendix H

Baseline SD Model Formulas

This appendix provides a tabulated version of the baseline simulation SD model.

- The variables are sorted by model sector, and where necessary grouped by material flows (e.g. cars/ELVs with associated variables, competition with associated variables)

- For each variable and stock, the formula or initial stock value is provided as well as a description of the variable equation or value and the unit.

- Additional notes, where applicable, are provided such as sources of data and/or rationale for the formulation of the variable.

- The shown variable values are as entered in the simulation software, STELLA version 10.0.4 which provides an equation view of the model that shows inflows/outflows and values as time differential equations. By giving the reader the variable values as entered by the modeller instead of a differential equations representation, it is hoped that better clarity and easier model reproduction is achieved.

- For the graphical representation of the model, please refer to the relevant figures of the model sectors in Section 6.2.
## APPENDIX H. BASELINE SD MODEL FORMULAS

<table>
<thead>
<tr>
<th>Model Sector</th>
<th>Unit Flows</th>
<th>Variable (<strong>bold &amp; underlined</strong> if a stock)</th>
<th>Formula or Value</th>
<th>Description</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELV Supply</td>
<td>ELVs</td>
<td>Actual New Car Sales</td>
<td>Year Value</td>
<td>Number of Cars. Use actual sales figures for PMV/LCV between 1993 and 2012</td>
<td>AAI (2009); ABS (2013)</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>1993 540403</td>
<td></td>
<td></td>
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<td>2003 885678</td>
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<td></td>
<td></td>
<td>2004 926748</td>
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<td>2006 931032</td>
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<td>2009 909773</td>
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<td>2010 941585</td>
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<td></td>
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<td>2011 980390</td>
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<td></td>
<td></td>
<td></td>
<td>2012 1080780</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>New Car Sales</td>
<td>if time&lt;2013 then Actual New Car Sales ELSE round(Fleet*0.06796)</td>
<td>Number of new cars entering the fleet</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vehicles Attritioned</td>
<td>New Car Sales * 0.62324</td>
<td>Number of cars becoming ELVs</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Scrapped</td>
<td>ELVs on Market * 0.2</td>
<td>ELVs taken off market by metal recyclers or exporters</td>
<td></td>
</tr>
<tr>
<td>Model Sector</td>
<td>Unit Flows</td>
<td>Variable (bold &amp; underlined if a stock)</td>
<td>Formula or Value</td>
<td>Description</td>
<td>Notes</td>
</tr>
<tr>
<td>--------------</td>
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<td>---------------------------------------</td>
<td>-----------------</td>
<td>-------------</td>
<td>-------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Acquired</td>
<td>round(ELVs on Market)</td>
<td>ELVs bought by the automotive recycling industry. The formula rounds off the value of the ELVs on Market stock after the scrapped ones are removed</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dispose</td>
<td>ELVs in Yard</td>
<td>ELVs acquired in the previous year are sold</td>
<td>Assume all ELVs acquired are disposed off each year</td>
</tr>
<tr>
<td>Fleet</td>
<td></td>
<td>9536532</td>
<td>Number of vehicles in the Australian fleet in 1992. AAI2010</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ELVs on Market</td>
<td>0</td>
<td>Number of ELVs on the market</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ELVs in Yard</td>
<td>0</td>
<td>Stock of ELVs with recyclers</td>
<td></td>
<td></td>
<td>To help determine ELV dismantling rate</td>
</tr>
<tr>
<td>Competition for ELVs - dimensionless metric</td>
<td>Increase</td>
<td>Acquired * Total Number of Auto Recyclers / 1300000</td>
<td>Competition is driven by the total number of automotive recyclers (legitimate and backyarders) and number of ELVs acquired</td>
<td>This flow may be seen as redundant to the model but it represents an explicit interpretation to how the ELV market price is eventually calculated</td>
<td></td>
</tr>
</tbody>
</table>
**APPENDIX H. BASELINE SD MODEL FORMULAS**

<table>
<thead>
<tr>
<th>Model Sector</th>
<th>Unit Flows</th>
<th>Variable (bold &amp; underlined if a stock)</th>
<th>Formula or Value</th>
<th>Description</th>
<th>Notes</th>
</tr>
</thead>
</table>
|              |            | Decrease                                | if time<2002 then Acquired * 1.05 / 1000  
Else ELVs on Market / 1650 | Competition decrease is assumed to follow a low rate prior to the model horizon (2003-2023), then directly calculated from the number of ELVs on Market from 2003 onward | |
<p>|              |            | Competition for ELVs                    | 1               | Dimensionless stock depicting competition for ELVs on the market | |
| ELV Demand Pressure - Dollars | Demand Differential | Increase*1.3-Decrease | ELV Demand Pressure is assumed increasing always | To help compute the ELV market price | |
|              | Drain      | ELV Demand Pressure                     | ELV Demand Pressure is not stocked | This calculation is used to reset the stock at every step | |
| ELV Demand Pressure | 0          | In dollars                              |                 | To help determine the component of market price for ELVs resulting from competition for ELVs | |</p>
<table>
<thead>
<tr>
<th>Model Sector</th>
<th>Unit Flows</th>
<th>Variable (bold &amp; underlined if a stock)</th>
<th>Formula or Value</th>
<th>Description</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>ELV Market Price</td>
<td>$2 \times (388 + \text{ELV Demand Pressure})$</td>
<td>In dollars. Price based on the Demand Pressure calculation. Multiplied by 2 to include all associated purchase costs (e.g. auction fees, transport to premises, advertising,) The $388 value is based on an average from real data from an automotive recycler</td>
<td>To help determine ELV Purchase Costs borne by the industry</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ELV Purchase Costs</td>
<td>ELV Market Price * Acquired / 1000000</td>
<td>In millions of dollars</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Scrap Index</td>
<td>Year</td>
<td>Value</td>
<td>Use reported scrap index figures between 2003 and 2012</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2003</td>
<td>35.375</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2004</td>
<td>41.15</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2005</td>
<td>53.725</td>
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<td></td>
<td></td>
<td>2006</td>
<td>68.575</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2007</td>
<td>74.975</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2008</td>
<td>89.575</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2009</td>
<td>74.025</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2010</td>
<td>91.35</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2011</td>
<td>106</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2012</td>
<td>87.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Scrap Metal Price</td>
<td>if time &lt; 26 then 2.13 * Scrap Index else 1.03 * previous(self,0)</td>
<td>In dollars. Assume scrap index is under reported by a factor of 2.13. From 2014 apply a compounded 3% on the 2013 value</td>
<td></td>
</tr>
</tbody>
</table>
## APPENDIX H. BASELINE SD MODEL FORMULAS

<table>
<thead>
<tr>
<th>Model Sector</th>
<th>Unit Flows</th>
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<th>Formula or Value</th>
<th>Description</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scrapped ELV Weight</td>
<td></td>
<td>1.233 tonnes between 2003 and 2008 1.121 tonnes from 2008 onward</td>
<td>Values represent weight left over after dismantling. Vehicles attritioned from around 2013 are lighter based on the dismantling trial data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scrap Metal Revenue</td>
<td>Dispose * Scrapped ELV Weight * Scrap Metal Price / 1000000</td>
<td>In millions of dollars</td>
<td>To help determine the industry revenue from the sale of Scrap Metals in ELVs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parts Storage Density</td>
<td>Dismantled Parts/Total Area Size</td>
<td>Parts/SQM. A metric to help determine the decision to reduce ELV dismantling rate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dismantle</td>
<td>if Parts Storage Density &gt; 2.5 then Dismantle ELVs in Yard * 24 else ELVs in Yard * 27</td>
<td>Dismantle as usual, but reduce by ~10% when the premises are filling up with parts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demand for Used Parts</td>
<td>Year</td>
<td>Value</td>
<td>Use reported demand between 2004 and 2012. Assume demand is exogenous</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2004</td>
<td>0.082</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2005</td>
<td>0.037</td>
<td>IBISWorld (2011)</td>
<td></td>
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<tr>
<td></td>
<td>2006</td>
<td>0.002</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>2007</td>
<td>0.009</td>
<td></td>
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</tr>
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<td>2008</td>
<td>-0.025</td>
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<td>0.015</td>
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<td>2011</td>
<td>-0.004</td>
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</tr>
<tr>
<td></td>
<td>2012</td>
<td>0.02</td>
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<tr>
<td>Model Sector</td>
<td>Unit Flows</td>
<td>Variable (if a stock)</td>
<td>Formula or Value</td>
<td>Description</td>
<td>Notes</td>
</tr>
<tr>
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<td>-------</td>
</tr>
<tr>
<td>Simulated Demand for Parts</td>
<td>if time &lt;2013 then Demand for Used Parts else normal(0.01478, 0.0306, 15000)</td>
<td>Use reported data until 2012 then a normalised trace value for which the behaviour is similar to the reported data in the previous years</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sell Parts</td>
<td>if time&gt;2002 Dismantled Parts*(0.9+Simulated Demand for Parts) else Dismantled Parts</td>
<td>Parts sold. Demand is continuously strong, Simulated Demand for Parts marginally influences the rate of parts sales</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parts Revenue</td>
<td>Sell Parts*Average_Sale Price per Part / 1000000</td>
<td>In millions of dollars</td>
<td>To help determine the industry revenue from the sale of Parts in ELVs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Sale Price per Part</td>
<td>87.3</td>
<td>In dollars, based on unpublished data provided from an automotive recycler covering 4 years of sales (2009-2013)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Dismantled Parts</td>
<td>0</td>
<td>In units. Stock of used parts removed from ELVs</td>
<td>To help determine Parts Storage Density</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Premises</td>
<td>Cost per sqm</td>
<td>11.22</td>
<td>In dollars</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**
- **Premises Area Size:**
  - Grow: if time>2002 and Profit>0 then LN(260 * Profit / Revenue) * 86 else 0
  - In sqm. Grow premises when profit of previous year is positive

**Unit Flows:**
- **Model:**
  - Sector
- **Variable (bold & underlined if a stock):**
  - Formula or Value
  - Description
  - Notes
<table>
<thead>
<tr>
<th>Model Sector</th>
<th>Unit Flows</th>
<th>Variable (bold &amp; underlined if a stock)</th>
<th>Formula or Value</th>
<th>Description</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Total Area Size</td>
<td>Enterprises * Premises Area Size</td>
<td>In sqm. Calculates premises area size used by all legitimate automotive recyclers</td>
<td>Used to determine Parts Storage Density</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Premises Costs</td>
<td>Premises Area Size * Cost per SQM * Enterprises / 1000000</td>
<td>In millions of dollars.</td>
<td>To help determine costs of premises borne by the industry</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Premises Efficiency</td>
<td>Profit / Premises Costs</td>
<td>A dimensionless metric to help determine the decision to shrink premises</td>
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<tr>
<td></td>
<td></td>
<td>Shrink</td>
<td>if time&lt;2003 then 0 else if (Premises Efficiency &lt;0.5) and Premises Efficiency &gt;0 Then 1121 Else 0</td>
<td>In sqm. Only shrink by about 20% when efficiency is between 0 and 0.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Premises Area Size</td>
<td>5300</td>
<td>In sqm. Estimated average area size of an automotive recycling business in 2003. Based on the areal survey study in Section 5.3.</td>
<td></td>
</tr>
<tr>
<td>Workforce</td>
<td>Workers</td>
<td>Hire</td>
<td>if time&gt;2002 and Profit Revenue Ratio&gt;0 then round(9*LN(260 * Profit Revenue Ratio)) else 0</td>
<td>Only hire if profit of previous year is positive. Begin with 2003 to model against available data</td>
<td></td>
</tr>
<tr>
<td>Model Sector</td>
<td>Unit Flows</td>
<td>Variable (bold &amp; underlined if a stock)</td>
<td>Formula or Value</td>
<td>Description</td>
<td>Notes</td>
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<tr>
<td></td>
<td></td>
<td>Dismiss</td>
<td>if time&lt;2003 then 0 [] else if Profit Revenue Ratio =0 then 360 else if (Workforce Efficiency &lt;0.57) then round( 0.05* Workforce Size) else round( 9<em>LN(260</em> Profit Revenue Ratio))</td>
<td>Only dismiss when efficiency drops or profit of previous year is negative (ratio becomes 0). Begin with 2003 to model against available data</td>
<td></td>
</tr>
<tr>
<td>Workforce Efficiency</td>
<td>Profit / Workforce Costs</td>
<td></td>
<td></td>
<td>A dimensionless metric to help determine the decision to dismiss workers</td>
<td></td>
</tr>
<tr>
<td>Average Wage</td>
<td></td>
<td>Year Dollars</td>
<td>Use wage figure between 2003 and 2012</td>
<td></td>
<td>IBISWorld (2011)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2003</td>
<td>46029</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2004</td>
<td>46650</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2005</td>
<td>46849</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2006</td>
<td>45628</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2007</td>
<td>43983</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2008</td>
<td>43324</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2009</td>
<td>42795</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2010</td>
<td>42572</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2011</td>
<td>41111</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2012</td>
<td>41672</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Workforce Costs</td>
<td></td>
<td>if time &lt;2003 then Workforce Size<em>46029/1000000 [] else if time &lt;2013 then Workforce Size</em>Average Wage /1000000 else 1.01*previous(self,0)</td>
<td>In millions of dollars. Use available data for 2003-2012, then $41.6k compounded by 1% per year from 2013 onward</td>
<td>To help determine costs of workforce borne by the industry</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Model Sector</th>
<th>Unit Flows</th>
<th>Variable (bold &amp; underlined if a stock)</th>
<th>Formula or Value</th>
<th>Description</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workforce Size</td>
<td></td>
<td>New</td>
<td>if time&lt;2003 then 0 else 1+ (Industry Reputation * 9)</td>
<td>Number of employees in the industry IBISWorld (2011)</td>
<td></td>
</tr>
<tr>
<td>Industry Image</td>
<td></td>
<td>Businesses Folding</td>
<td>if time&lt;2003 then 0 else if Profit Revenue Ratio &gt;0 then 2+(1/Profit Revenue Ratio) else 8</td>
<td>Businesses folding due to financial reasons assumed about 8 a year (1% approx) but while profits are high, folding rate decreases</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total Number of Auto Recyclers + Backyarders</td>
<td>Enterprises + Backyarders</td>
<td>Combined total number of recyclers</td>
<td></td>
</tr>
<tr>
<td>Licensing and Enforcement</td>
<td></td>
<td>1</td>
<td>Dimensionless. Assume current level of 1 is non-existing requirements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environmental Impact</td>
<td></td>
<td>Backyarders / (Enterprises * Licensing and Enforcement)</td>
<td>Dimensionless. More backyarders, less licensing and enforcement results in higher environmental impact</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model Sector</td>
<td>Unit Flows</td>
<td>Variable (bold &amp; underlined if a stock)</td>
<td>Formula or Value</td>
<td>Description</td>
<td>Notes</td>
</tr>
<tr>
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<td>------------------------------------------</td>
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<td>-------------</td>
<td>-------</td>
</tr>
<tr>
<td>Industry Reputation</td>
<td></td>
<td>2* Profit Revenue Ratio<em>Enterprises / ((1+ Backyarders)</em>(1+ Environmental Impact))</td>
<td>Dimensionless metric.</td>
<td>Highly profitable industry with small illegitimate competition and lower environmental impact make the industry more appealing to new entrants as well as conversions from backyarders to legitimate operations</td>
<td></td>
</tr>
<tr>
<td>Creation Rate</td>
<td>20</td>
<td></td>
<td>Dimensionless metric.</td>
<td></td>
<td>To help determine rate of backyarders coming into business</td>
</tr>
<tr>
<td>Created</td>
<td>if time&lt;2003 then 0 else Backyarders / Creation Rate</td>
<td>Backyarders. Only start in 2003 having new backyarders to help match trend of enterprises/backyarders ratio for 2003-2012</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Legitimised</td>
<td>if time&lt;2003 then 0 else round( Industry Reputation * Backyarders /Legitimisation Ratio)</td>
<td>Backyarders becoming legitimate recyclers. Only start in 2003 having new backyarders to help match trend of enterprises/backyarders for 2003-2012</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## APPENDIX H. BASELINE SD MODEL FORMULAS

<table>
<thead>
<tr>
<th>Model Sector</th>
<th>Unit Flows</th>
<th>Variable (bold &amp; underlined if a stock)</th>
<th>Formula or Value</th>
<th>Description</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legitimisation Ratio</td>
<td></td>
<td>1250</td>
<td>Dimensionless metric. The bigger the ratio the less likely that backyarders convert into legitimate recyclers</td>
<td>To help determine rate of backyarders becoming legitimate operators</td>
<td></td>
</tr>
<tr>
<td>Folded</td>
<td>if time&lt;2003 then 0 else ROUND(Created / Folding Rate)</td>
<td>Backyarders folding. Only start in 2003 having new backyarders to help match trend of enterprises/backyarders ratio for 2003-2012</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Folding Rate</td>
<td></td>
<td>4</td>
<td>Dimensionless metric. To help determine rate of backyarders folding operations. Assume creation to folding rate is 5 to 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enterprises</td>
<td></td>
<td>853</td>
<td>Number of legitimate automotive recyclers in 2003.</td>
<td>Also to help determine the total number of recyclers, the total area size of premises used by the industry, and associated costs. IBISWorld (2011)</td>
<td></td>
</tr>
<tr>
<td>Model Sector</td>
<td>Unit Flows</td>
<td>Variable (bold &amp; underlined if a stock)</td>
<td>Formula or Value</td>
<td>Description</td>
<td>Notes</td>
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<td>-------------</td>
<td>-------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Backyarders</td>
<td>100</td>
<td>Number of backyarders in 2003. Estimate based on discussion with industry stakeholders - about 1 in 10 of operators.</td>
<td>To help determine the total number of recyclers</td>
</tr>
<tr>
<td>Financial</td>
<td>Revenue /Profit /Expenditure in millions of dollars</td>
<td>Revenue from Sales</td>
<td>In million of dollars</td>
<td>To help determine Profit Revenue ratio</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Revenue from Sales</td>
<td>Parts Revenue + Scrap Metal Revenue</td>
<td>In million of dollars</td>
<td>Redundant variable, added to better represent the diagram</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Profit Revenue Ratio</td>
<td>if time&gt;2002 and Profit&gt;0 then (previous(Profit,0.087)) / Revenue else 0.06</td>
<td>Dimensionless metric. Only begin calculation from 2003 onward. Assume 0 if profit is nil or negative to avoid division by zero error. Uses Profit from last year.</td>
<td>To help determine Businesses Folding and Industry Reputation variables</td>
<td></td>
</tr>
<tr>
<td>Model Sector</td>
<td>Unit Flows</td>
<td>Variable (bold &amp; underlined if a stock)</td>
<td>Formula or Value</td>
<td>Description</td>
<td>Notes</td>
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<tr>
<td></td>
<td></td>
<td><strong>Profit</strong></td>
<td>if time&lt;2003 then 0 else Revenue-1.25 * Expenditure</td>
<td>In millions of dollars. Assume expenditure for other matters than workforce / premises / purchase costs about 25% of the subtotal</td>
<td>To help determine workforce hiring/dismissal, premises growth, workforce efficiency, and premises efficiency rates</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Expenditure</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Business Costs</strong></td>
<td>In millions of dollars</td>
<td>Redundant variable, added to improve the diagram clarity</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Business Costs</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Workforce Costs + Premises Costs + ELV Purchase Costs</strong></td>
<td>In millions of dollars</td>
<td>Redundant variable, added to better represent the diagram</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Cash flow</strong></td>
<td>0</td>
<td>In millions of dollars</td>
<td>Redundant stock. used to calculate cash reserves</td>
</tr>
</tbody>
</table>
Appendix I

Scenarios Data Analysis Grid

This appendix documents the qualitative data analysis of the scenarios effects on the model to identify new and modifications to variables, the updated causal links, and the assumptions for values where applicable.

The analysis is organised by scenario in separate sections and tables and model sectors (as rows within the tables).
### I.1 Scenario A - Smart Auto Waste

<table>
<thead>
<tr>
<th>Model Sectors / Focus Areas</th>
<th>Effects</th>
<th>Observation</th>
<th>Identified Variables (Codes)</th>
<th>CLD Updates</th>
<th>SFD Updates</th>
<th>Justifying the SFD Updates</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply of damaged old vehicles licensing increases supply</td>
<td>National licensing increases supply</td>
<td>Reduction of the number of operators, both legitimate and backyarders will lessen ELV demand, which translates in lower ELV purchase costs. Harmonising the licensing across states and territories also means that competition for ELV stock from interstate buyers will lessen (not at an aggregate level), though this segmentation is not considered in the model scope. Because the changes in values occur in the industry image and reputation sector, no additional codes are needed to represent this effect.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>- Level of and quality of ELV supply because recyclers may have less incentive to source out ELVs from secondary sources. - Could this increase ELV abandoning, or prolong use of older vehicles?</td>
<td></td>
</tr>
</tbody>
</table>
## Demand for used parts

<table>
<thead>
<tr>
<th>Sectors / Focus Areas</th>
<th>Effects</th>
<th>Observation</th>
<th>Identified Variables (Codes)</th>
<th>CLD Updates</th>
<th>SFD Updates</th>
<th>Justifying the SFD Updates</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand for used parts</td>
<td>Reduced demand for parts</td>
<td>As comparative cost of ownership of new vehicles is more attractive than maintaining older cars, early retirement of vehicles becomes more common resulting in lower demand for used parts, particularly for vehicles under than 10 years that currently constitute a major market for auto recyclers. Assume a decay of about 2% per annum</td>
<td>Demand Downshift for Used Parts</td>
<td>Add Demand Downshift for Used Parts to Demand for Used Parts</td>
<td>Modify formula of “Simulated Demand for Parts” to introduce a demand downshift from Year 25 (2013)</td>
<td>Demand downshift should skew the Demand for parts variable into negative values, resulting in less parts sold</td>
<td>- Despite a lowered demand more parts continue to be dismantled and sold</td>
</tr>
</tbody>
</table>

## Premises / Land related

<p>| Compliance | Increased costs associated with licensing and / or enforcement levied by government / industry body. Additional equipment costs are also assumed | Compliance Costs | Add Compliance Costs to Premises Costs | Introduce Compliance Costs as 5 percent increase on Premises Costs. | Assumed compliance costs as an annual 5 percent of premises costs, representing ongoing investments and capital investments spread out over a decade. | Sensitivity analysis based on compliance costs alone. |</p>
<table>
<thead>
<tr>
<th>Model Sectors / Focus Areas</th>
<th>Effects</th>
<th>Observation</th>
<th>Identified Variables (Codes)</th>
<th>CLD Updates</th>
<th>SFD Updates</th>
<th>Justifying the SFD Updates</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labour related</td>
<td>Mixed skills</td>
<td>Workers require additional skill set to cope with the shift in the line of business. This will translate into higher labour costs assuming workforce size remains the same</td>
<td>Marginal Training Costs</td>
<td>Add Marginal Training Costs to Workforce Costs</td>
<td>Introduce Marginal Workforce Costs as a 7 percent increase of Workforce Costs from year 25 (2013)</td>
<td>Assumed a 3000 dollar training / certification cost per worker which represents about 7 percent of average salary. The increase remains for subsequent years because of increasing wages for the additional skills acquired</td>
<td>May need to rework baseline to induce a higher hiring rate</td>
</tr>
<tr>
<td>Model Sectors / Focus Areas</td>
<td>Effects</td>
<td>Observation</td>
<td>Identified Variables (Codes)</td>
<td>CLD Updates</td>
<td>SFD Updates</td>
<td>Justifying the SFD Updates</td>
<td>Notes</td>
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</tr>
<tr>
<td>Industry image and reputation</td>
<td>Increased due to necessity to regulate</td>
<td>A regulated industry with minimised competition from backyarders will likely translate into a smaller but more profitable industry. The environmental impact will be reduced resulting in an improved industry reputation. However, because of the shift in business model that the industry may need to follow there will be a drop in the number of new backyarders and a surge of businesses, both legitimate and backyarder, folding</td>
<td>-</td>
<td>Link Licensing and Enforcement to Backyarders Folding / Legitimisation rates as a multiple.</td>
<td>Link Licensing and Enforcement to Backyarders Folding / Legitimisation rates</td>
<td>Licensing and enforcement policies target illegitimate operators, either forcing them to fold or become legitimate operators that are part of the industry.</td>
<td>L&amp;E do not need to link directly to Environmental Impact, as compliance of current operators is assumed exogenous to the model.</td>
</tr>
</tbody>
</table>

Justifying the SFD Updates

License and Enforcement policies target illegitimate operators, either forcing them to fold or become legitimate operators that are part of the industry.
## I.2 Scenario B - How it Should Be

<table>
<thead>
<tr>
<th>Model</th>
<th>Effects</th>
<th>Observation</th>
<th>Identified Variables (Codes)</th>
<th>CLD Updates</th>
<th>SFD Updates</th>
<th>Justifying the SFD Updates</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Supply of damaged old vehicles</strong></td>
<td>Level playing field, Backyards removed</td>
<td>Similar to scenario A, Reduction of the number of operators, through the removal of backyards will lessen ELV demand, which translates in lower ELV purchase costs. Because the changes in values occur in the industry image and reputation sector, no additional codes are needed to represent this effect.</td>
<td>Marginal Demand for Used Parts</td>
<td>Add Marginal Demand for Used Parts</td>
<td>Modify formula of “Simulated Demand for Parts” to introduce a demand up shift from Year 25 (2013).</td>
<td>Marginal Demand should skew the Demand for parts variable resulting in higher rate of parts sold.</td>
<td></td>
</tr>
<tr>
<td><strong>Demand for used parts</strong></td>
<td>Increased demand, Good value</td>
<td>Participants assume that demand for used parts will increase dependent on the affordability of new vehicles</td>
<td>Marginal Demand for Used Parts</td>
<td>Add Marginal Demand for Used Parts</td>
<td>Introduce Marginal Demand for Used Parts</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td><strong>Premises / Land related</strong></td>
<td>Larger premises, productivity</td>
<td>Increase premises size to cope with higher turnover, expand business into other localities, and/or invest in process improvement. The three effects can be translated through an increment in costs and premises area size.</td>
<td>Marginal Premises Costs</td>
<td>Add Marginal Premises Costs</td>
<td>Introduce Marginal Premises Costs as 5 percent increase on Premises Costs from Year 25.</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Model</td>
<td>Effects</td>
<td>Observation</td>
<td>Identified</td>
<td>CLD Updates</td>
<td>SFD Updates</td>
<td>Justifying the SFD Updates</td>
<td>Notes</td>
</tr>
<tr>
<td>----------------</td>
<td>---------</td>
<td>------------------------------------------------------------------------------</td>
<td>------------</td>
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<td>-------------</td>
<td>--------------------------</td>
<td>---------</td>
</tr>
<tr>
<td><strong>Labour</strong></td>
<td>More staff required, higher waged attracting people to industry</td>
<td>As a result of higher demand for used parts and the availability of ELVs on the market, the industry will need to grow its workforce to cope with the perceived increased demand and might have to increase wages in order to attract more people to the industry. The effect of significantly increasing wage costs may impact on industry profits in the long run</td>
<td>Marginal Premises, Premises Growth to Premises Area Size</td>
<td>Add Marginal Premises, Premises Growth to Premises Area Size</td>
<td>Increase rate of Premises growth by 5 percent.</td>
<td>Combining both increases should result in further expansion of premises over baseline</td>
<td>-</td>
</tr>
<tr>
<td><strong>Industry</strong></td>
<td>Image improvement, environmental leaders</td>
<td>A regulated industry with minimised competition from backyarders will likely translate into a smaller but more profitable industry. The environmental impact will be reduced resulting in an improved industry reputation. Assumptions made in Scenario A for this sector can be carried over</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Introduce Marginal Workforce Costs as a 10 percent increase of Workforce Costs from Year 25 (2013).</td>
<td>-</td>
</tr>
</tbody>
</table>
## I.3 Scenario C - Wild West

<table>
<thead>
<tr>
<th>Model</th>
<th>Effects</th>
<th>Observation</th>
<th>Identified Variables (Codes)</th>
<th>CLD Updates</th>
<th>SFD Updates</th>
<th>Justifying the SFD Updates</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sectors / Focus Areas</td>
<td>Auction houses</td>
<td>Current trends continue as base model</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Supply of damaged old vehicles</td>
<td>Unfettered, Shit fight, Bidding against anybody, eBay</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demand for used parts</td>
<td>High/low,</td>
<td>Current trends continue as base model although demand on parts will remain strong - Carry over from Scenario B</td>
<td>Marginal</td>
<td>Add Marginal Demand for Used Parts to Demand for Used Parts</td>
<td>Modify formula of &quot;Simulated Demand for Parts&quot; to introduce a demand increase from Year 25 (2013)</td>
<td>Marginal Demand should skew the Demand for parts variable resulting in higher rate of parts sold.</td>
<td></td>
</tr>
<tr>
<td>Premises / Land related</td>
<td>No licensing or regulation, Land tax we pay, Backyarder doesn’t, Trade waste agreements</td>
<td>Current trends continue as base model</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labour related</td>
<td>Business not OHS standards, Open to undesirables</td>
<td>Current trends continue as base model</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industry image and reputation</td>
<td>People think we are Neanderthals, &quot;uncouth&quot;</td>
<td>Current trends continue as base model</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## I.4 Scenario D - Big Drama / Downward Spiral

<table>
<thead>
<tr>
<th>Model Sectors / Focus Areas</th>
<th>Effects</th>
<th>Observation</th>
<th>Identified Variables (Codes)</th>
<th>CLD Updates</th>
<th>SFD Updates</th>
<th>Justifying the SFD Updates</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply of damaged old vehicles</td>
<td>Dramatic reduction in vehicle prices</td>
<td>With the reduction of revenue potential from ELVs as parts, both auto recyclers and backyarders will be willing to pay less for ELVs which will force down the price of ELVs</td>
<td>ELV Demand Downstep</td>
<td>-</td>
<td>Add ELV Demand</td>
<td>Downstep factor (0.8) from Year 25 (2013), modify Decrease variable to include it</td>
<td>-</td>
</tr>
<tr>
<td>Demand for used parts</td>
<td>Greatly reduced Demand for parts will eventually get reduced but meanwhile the demand for current models will decay</td>
<td>Demand Add Demand Downshift for Used Parts to Demand for Used Parts</td>
<td>Add Demand Downshift for Used Parts</td>
<td>Modify formula of “Simulated Demand for Parts” to introduce a demand downshift by 0.2 from Year 25 (2013)</td>
<td>Demand downshift should skew the Demand for parts variable into negative values, resulting in less parts sold</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Model</td>
<td>Effects</td>
<td>Observation</td>
<td>Identified Variables (Codes)</td>
<td>CLD Updates</td>
<td>SFD Updates</td>
<td>Justifying the SFD Updates</td>
<td>Notes</td>
</tr>
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<td>-------</td>
</tr>
<tr>
<td>Premises / Land related</td>
<td>Downsize, sale</td>
<td>Less turnover will lead to having to scale down operations or even fold business thereby reducing the size of the premises. No change necessary as the dynamic is already captured as per the baseline model. The part about folding business is already captured because the premises area size variable is modelled as dependent on the combined turnover of the industry. There will be a subsequent increase in combined area size because of the turnover of folded businesses being shifted to competitors / other recyclers.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Model Sectors / Focus Areas</td>
<td>Effects</td>
<td>Observation</td>
<td>Identified Variables (Codes)</td>
<td>CLD Updates</td>
<td>SFD Updates</td>
<td>Justifying the SFD Updates</td>
<td>Notes</td>
</tr>
<tr>
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</tr>
<tr>
<td>Labour</td>
<td>Costs will outweigh sale of materials</td>
<td>Workers may require additional skill set to cope with the shift in the line of business. This will translate into higher labour costs assuming workforce size remains the same</td>
<td>Marginal Training Costs</td>
<td>Add to</td>
<td>Introduce</td>
<td>Marginal training/certification cost per worker which represents about 7 percent of average salary. The increase remains for subsequent years because of increasing wages for the additional skills acquired</td>
<td></td>
</tr>
<tr>
<td>Industry image and reputation</td>
<td>No industry, no reputation, you don’t help people any more</td>
<td>Industry reputation will continue to decrease with no prospects for bouncing back. Environmental impact will increase with the absence of enforceable laws / guidelines</td>
<td>Already captured</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Appendix J

Scenarios SD Model Updates

This appendix provides a tabulated summary of the variables changed and/or added to the Scenario-based simulation SD models.

- For each scenario, a copy of the baseline model was made then the variables were changed or updated.

- Only the the changed or added variables are listed. All unlisted variables remain as per the baseline model.

- No variables were removed from the baseline model.

### J.1 Scenario A - Smart Auto Waste

<table>
<thead>
<tr>
<th>Model Sector</th>
<th>Unit Flows</th>
<th>Variable</th>
<th>Formula or Value</th>
<th>Description</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parts</td>
<td>Dismantled Parts</td>
<td>Simulated Demand for Parts</td>
<td>if time &lt;2013 then Demand for Used Parts else normal(0.01478, 0.0306, 15000) + Demand Downshift</td>
<td>Use reported data until 2012 then from 2013 apply a normalised trace value, for which the behaviour is similar to the reported data in the previous years, downshifted by 0.2</td>
<td>Use reported data until 2012 then from 2013 apply a normalised trace value, for which the behaviour is similar to the reported data in the previous years, downshifted by 0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Demand Downshift</td>
<td>-0.2</td>
<td>20% downward shift in the rate of sold parts</td>
<td></td>
</tr>
<tr>
<td>Model Sector</td>
<td>Unit Flows</td>
<td>Variable</td>
<td>Formula or Value</td>
<td>Description</td>
<td>Notes</td>
</tr>
<tr>
<td>--------------</td>
<td>------------</td>
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<td>------------------</td>
<td>-------------</td>
<td>-------</td>
</tr>
<tr>
<td>Premises</td>
<td>Premises Area Size</td>
<td>Compliance Costs</td>
<td>if time &gt;2012 then 1.05 else 1</td>
<td>Dimensionless metric only applied from 2013 onwards to add 5% to Premises Costs</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Premises Costs</td>
<td>Compliance Costs * Premises Area Size * Cost per SQM * Enterprises / 1000000</td>
<td>In millions of dollars</td>
<td></td>
</tr>
<tr>
<td>Workforce</td>
<td>Workers</td>
<td>Workforce Costs</td>
<td>if time &lt;2003 then Workforce Size * 46029 / 1000000 else if time &lt;2013 then Workforce Size * Average Wage / 1000000 else if time=2013 THEN Marginal Workforce Costs * previous (self, 0) else 1.01 * previous(self, 0)</td>
<td>In millions of dollars. Use available data for 2003-2012, then 41.6k multiplied by marginal increase in 2013 onwards, then 1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Marginal Workforce Costs</td>
<td>1.07</td>
<td>7% upward shift in added workforce costs</td>
<td></td>
</tr>
<tr>
<td>Industry Image</td>
<td>Legitimate automotive recyclers and backyards</td>
<td>Licensing and Enforcement</td>
<td>if time&lt;2013 then 1 else 2</td>
<td>Dimensionless. Assume current level of 1 is non-existent requirements. Becomes 2 from 2013 onwards</td>
<td></td>
</tr>
</tbody>
</table>

To help determine Environmental Impact, Industry Reputation and Folding Rate of Backyarders
### APPENDIX J. SCENARIOS SD MODEL UPDATES

<table>
<thead>
<tr>
<th>Model Sector</th>
<th>Unit Flows</th>
<th>Variable</th>
<th>Formula or Value</th>
<th>Description</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Environmental Impact</td>
<td></td>
<td>Dimensionless. The more backyarders and/or less enterprises means higher environmental impact</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Backyarders / Enterprises</td>
<td></td>
<td>Licensing and Enforcement is removed, assumed licensed enterprises all adhere to EPA requirements and best practice guidelines</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Legitimisation Rate</td>
<td>if time &lt; 2013 then 1250 else Licensing and Enforcement</td>
<td>Dimensionless metric. Similar to Legitimisation Ratio in the baseline model until 2013 when it effectively doubles the rate</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Folding Rate</td>
<td>if time &lt; 2013 then 4 else 0.4/ Licensing and Enforcement</td>
<td>Dimensionless metric. Effective increase in folding rate by 25%,</td>
<td></td>
</tr>
</tbody>
</table>

### J.2 Scenario B - How it Should Be

<table>
<thead>
<tr>
<th>Model Sector</th>
<th>Unit Flows</th>
<th>Variable</th>
<th>Formula or Value</th>
<th>Description</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parts</td>
<td>Dismantled Parts</td>
<td>Simulated Demand for Parts</td>
<td>if time &lt; 2013 then Demand for Used Parts else normal(0.01478, 0.0306, 15000) + Marginal Demand</td>
<td>Use reported data until 2012 then a normalised trace value, downshifted by , for which the behaviour is similar to the reported data in the previous years</td>
<td></td>
</tr>
</tbody>
</table>
### J.2. SCENARIO B - HOW IT SHOULD BE

<table>
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<tr>
<th>Model Sector</th>
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<th>Variable</th>
<th>Formula or Value</th>
<th>Description</th>
<th>Notes</th>
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<tbody>
<tr>
<td>Premises</td>
<td></td>
<td>Marginal Demand</td>
<td>0.5</td>
<td>50% upward shift in the rate of sold parts</td>
<td></td>
</tr>
<tr>
<td>Premises</td>
<td>Area Size</td>
<td>Compliance Costs</td>
<td>if time &gt;2012 then 1.05 else 1</td>
<td>Dimensionless metric only applied from 2013 onwards to add 5% to Premises Costs</td>
<td></td>
</tr>
<tr>
<td>Premises</td>
<td></td>
<td>Compliance Costs</td>
<td>Compliance Costs * Premses Area Size * Cost per SQM * Enterprises / 1000000</td>
<td>In millions of dollars</td>
<td></td>
</tr>
<tr>
<td>Workforce</td>
<td>Workers</td>
<td>Workforce Costs</td>
<td>if time &lt;2003 then Workforce Size * 46029 / 1000000 else if time &lt;2013 then Workforce Size * Average Wage / 1000000 else if time=2013 THEN Marginal Workforce Costs * previous (self, 0) else 1.01 * previous(self, 0)</td>
<td>In millions of dollars. Use available data for 2003-2012, then 41.6k multiplied by marginal increase in 2013 onwards, then 1</td>
<td></td>
</tr>
<tr>
<td>Workforce</td>
<td></td>
<td>Marginal Workforce Costs</td>
<td>1.14</td>
<td>14% upward shift in additional workforce costs</td>
<td></td>
</tr>
<tr>
<td>Industry</td>
<td></td>
<td>Licensing and Enforcement</td>
<td>if time&lt;2013 then 1 else 2</td>
<td>Dimensionless. Assume current level of 1 is non-existent requirements. Becomes 2 from 2013 onwards</td>
<td>To help determine Environmental Impact, Industry Reputation and Folding Rate of Backyarders</td>
</tr>
</tbody>
</table>
### Model Sector

<table>
<thead>
<tr>
<th>Model Sector</th>
<th>Unit Flows</th>
<th>Variable</th>
<th>Formula or Value</th>
<th>Description</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental Impact</td>
<td>Backyarders / Enterprises</td>
<td>Dimensionless metric.</td>
<td>The more backyards and/or less enterprises means higher environmental impact</td>
<td>Licensing and Enforcement is removed, assumed licensed enterprises all adhere to EPA requirements and best practice guidelines</td>
<td></td>
</tr>
<tr>
<td>Legitimisation Rate</td>
<td>if time &lt; 2013 then 1250 else Licensing and Enforcement</td>
<td>Dimensionless metric.</td>
<td>Similar to Legitimisation Ratio in the baseline model until 2013 when it effectively doubles the rate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Folding Rate</td>
<td>if time &lt; 2013 then 4 else 0.4/ Licensing and Enforcement</td>
<td>Dimensionless metric.</td>
<td>Effective increase in folding rate by 25%,</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Scenario C - Wild West

<table>
<thead>
<tr>
<th>Model Sector</th>
<th>Unit Flows</th>
<th>Variable</th>
<th>Formula or Value</th>
<th>Description</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parts</td>
<td>Dismantled Parts</td>
<td>Simulated Demand for Parts</td>
<td>if time &lt;2013 then Demand for Used Parts else normal(0.01478, 0.0306, 15000) + Marginal Demand</td>
<td>Use reported data until 2012 then a normalised trace value, downshifted by , for which the behaviour is similar to the reported data in the previous years</td>
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</table>
### J.4 Scenario D - Big Drama / Downward Spiral

<table>
<thead>
<tr>
<th>Model Sector</th>
<th>Unit Flows</th>
<th>Variable</th>
<th>Formula or Value</th>
<th>Description</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELV Supply</td>
<td>Competition for ELVs - dimensionless metric</td>
<td>Decrease</td>
<td>if time&lt;2003 then Acquired * 1.05/1000 else ELVs on Market * ELV Demand Downstep /1650</td>
<td>Competition decrease is assumed to follow a low rate prior to the model horizon (2003-2023), then directly calculated from the number of ELVs on Market from 2003 onwards</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ELV Demand Downstep</td>
<td>if time&lt;2013 then 1 else 1.2</td>
<td>20% drop in demand for ELVs from 2013</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parts</td>
<td>Dismantled Parts</td>
<td>Simulated Demand for Parts</td>
<td>if time &lt;2013 then Demand for Used Parts else normal(0.01478, 0.0306, 15000) + Demand Downshift</td>
<td>Use reported data until 2012 then a normalised trace value, downshifted by , for which the behaviour is similar to the reported data in the previous years</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Demand Downshift</td>
<td>-0.2</td>
<td>20% decrease in rate of sold parts</td>
<td></td>
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</tr>
<tr>
<td>Model Sector</td>
<td>Unit Flows</td>
<td>Variable</td>
<td>Formula or Value</td>
<td>Description</td>
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<td>-------</td>
</tr>
<tr>
<td>Workforce</td>
<td>Workers</td>
<td>Workforce Costs</td>
<td>if time &lt;2003 then Workforce Size * 46029 / 1000000 else if time &lt;2013 then Workforce Size * Average Wage / 1000000 else if time=2013 THEN Marginal Workforce Costs * previous (self, 0) else 1.01 * previous(self, 0)</td>
<td>In millions of dollars. Use available data for 2003-2012, then 41.6k multiplied by marginal increase in 2013 onwards, then 1</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Marginal Workforce Costs</td>
<td>1.07</td>
<td>7% upward shift in added workforce costs</td>
<td></td>
</tr>
</tbody>
</table>
Bibliography

AAA (2016) Who we are - Australian Automobile Association.


ACOR (2009) Who is ACOR.


Corona (1925) Biggest Auto Dump., *Logansport Pharos-Tribune*, p. 25.


Cuenot, F. (2009) CO2 emissions from new cars and vehicle weight in Europe; How the EU regulation could have been avoided and how to reach it?, *Energy Policy*, **37**, 3832–3842.


Ford (1930) River Rouge Plant; Recycling Model T Fords.


IDIS2 (2014) The International Dismantling Information System: IDIS.


MTAA (2015) Members - MTAA.


Snyder, J. (2011) No new cars, but that didn’t stop U.S. automakers, dealers during WWII.


Weatherhead, T. (2005) *A Study to Determine the Metallic Fraction Recovered from End of Life Vehicles in the UK: Report to the Department of Trade and Industry*, DTI.


