The Automobile Recycling Industry in North America

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Abstract

The automobile recycling industry in North America is a success story in material recovery. It operates unregulated, market driven. It is an example of how effectively self-profit-maximising parties, without interference, can manage recycling. Or at least, that is the claim.

However, reductions in vehicle weight and increases in plastic composition might undermine the future viability of the industry. This work assesses these threats and the influence that automakers have on the industry.

It is argued that if historical trends in vehicle composition continue, the automobile recycling industry will be destroyed. However, automakers have the opportunity to improve the viability of the industry, although common wisdom may not work: increases in the level of Design for Disassembly, for example, might not result in more recycling.

This work presents the Automobile Recycling Dynamic Model, which incorporates prices, physical flows, delays, and the industry participants' decision processes is the basis for this research.

Problem Definition - Context

The automobile recycling industry consists of interactions among four main bodies: the automobile manufacturers, consumers, dismantlers and shredders. Automakers are responsible for the material selection, the car weight and other design characteristics. Consumers of vehicles are the general public, who buy and later dispose of the cars. Dismantlers acquire de-registered cars and process them by removing some parts for reuse and some for remanufacture. They could dismantle vehicles to recover specific types of materials as well.

What is left after the dismantling is complete is called the *hulk*, and is sold to shredders, who process not only unwanted vehicles, but also appliances, and any other sources of scrap metal. Hulks are processed by feeding them into a large hammer mill (shredder) which rips them into fist-sized pieces. The ferrous pieces are removed with magnetic separation and sold to the steel mills. The non-ferrous metal pieces are isolated with technology such as eddy-current separators and reprocessed. The remainder is comprised of plastics, elastomers, glass, and other non-metals, as well as some leftover metals. This mixture is known as *Automotive Shredder Residue* (ASR) or auto fluff. Most of the fluff is sent to landfills. ASR represents one of the major environmental concerns associated with disposing of automobiles. It is also a pure cost to the recycling industry with a double negative impact: it increases processing costs (transportation and shredding) and requires an outflow of resources associated to the final disposal on landfills.

A major component of the interactions between the four bodies (automobile manufacturers, consumers, dismantlers and shredders) is economic in nature. Consumers pay when acquiring automobiles and they may receive money at the end of the automobile life cycle by selling the de-registered cars to dismantlers. Dismantlers receive money when selling recovered material and used parts. They also sell the hulks to shredders. Shredders, in turn, sell the recovered metals and have to pay for the disposal of the ASR. Finally, the production of automobiles demands steel and other metals which impact the price levels for scrap material, and therefore the price of de-registered cars and hulks.

The automotive recycling industry in North America dates back to times long before recycling and environmental consciousness were in vogue. Today it represents probably the most successful recycling story [Field *et al* 1994]. The industry processes retired cars and trucks at a rate of ten to twelve million per year. It is commonly recognised that this industry works efficiently because it is economically driven. In other words, each participant makes decisions seeking to optimise their monetary benefit, and by doing so the whole system is optimised.

It is estimated that approximately 94% of the vehicles being retired, or de-registered, are processed by the recycling industry. From these, approximately 75% of the total mass is recovered. The other 25% is ASR and is disposed in landfills. This is an industry that processes more than ten million tons of material per year.

It will be argued that it is not only the economic foundation what makes this industry a success. Technological development has also played a fundamental role by creating the conditions for economical recovery of metals. The development of the electric-arc furnace and the shredding technology solved the abandoning problem observed in the late 60s and early 70s.

There are two trends in automobile manufacturing, which in combination, cast doubts on the sustainability of this industry; a) reductions in the average weight of vehicles, and b) increases in the use of plastics in automobiles. The average weight of a passenger car in North America changed from 1,450kg in 1980 to 1,250kg in 1990. Although the average weight increased after 1990 to more than 1,300kg, it is estimated that the average weight in the future will continue to go down.

There are two key drivers for reductions in vehicle weight; one economic and one environmental. The economic driver has to do with the total cost of owning vehicles; fuel consumption is a major cost in the life time of a car and is directly proportional to the vehicle weight. The environmental driver is also associated to fuel consumption but it is mainly a consequence of recently mandated emission reduction goals.

The second trend that preoccupies the automobile recycling industry is the increase in use of plastics. In 1980, approximately 15% of the total mass of automobiles in North America was made of plastic. It is estimated that in 1995, this fraction was almost 20%. The reasons behind are mainly economic and performance related. More sophisticated resins and better manufacturing processes have allowed automobile manufacturers to simultaneously reduce production costs and increase vehicle performance by using more plastics.

The combined effect of these two trends are of concern because lighter vehicles with less proportion of metals will result in a reduction of profits for shredders. Reductions in the average car weight reduce the unit margin for shredded hulks, and more plastic increases the disposal costs. In consequence, the hulk value may go down and so will the price paid for hulks. This may result in a reduction of the profitability of dismantlers, which then, may need to paid lower prices for de-registered cars. When the value of de-registered cars is reduced, the cost of automobile collection may not be covered and old cars might simply be abandoned. This situation would reassemble the experience on the late 60's, when abandoned cars accumulated in lots and created an unacceptable damage to the environment.

In Europe, this threat is being assessed by governments and a series of regulations are under consideration. Two initiatives may be implemented; a disposal fee, and a mandate for automobile manufactures to take back de-registered vehicles for recycling and disposal. The first initiative is based on the notion that there is a real cost to society in properly disposing vehicles and therefore consumers should pay for it. The undesirable consequence, in the eyes of automakers, is that this increases the total cost of owning a vehicle. The second initiative is based on the belief that if the automobile manufacturers are held responsible for the recycling, they will do their best to increase recyclability. After all, recyclability is mainly defined at the design stage –material selection, and ease of disassembly are designed prior to the production stage. In the perspective of the automobile manufacturers this is undesirable because they consider that recycling is not part of their core business and would increase their total operating costs.

In North America, legislators have not yet considered any of these initiatives. This type of government intervention may not be necessary… as long as the automobile recycling industry keeps operating as well as it does today.

However, automakers in North America are aware of the threats and have engaged other parties to help the automobile recycling industry sustain its non-government-intervened structure. It is in their best interest to keep this industry running efficiently.

After a change in regulation that allows automobile manufacturers to fund and run non-competitive research programs Ford, Chrysler and General Motors established the United States Council for Automotive Research, the technical arm of the American Automobile Manufacturers Association. Under the umbrella of the automobile manufacturers several companies, including suppliers, have come together to perform common research.

The Vehicle Recycling Partnership (VRP) is one of the enterprises established to perform environmental research and development. The automakers were joined by collaborators such as the Automotive Recyclers' Association, the American Plastics Council, and the Institute of Scrap Recycling Industries, and others. The VRP was founded to identify and pursue opportunities for joint research and development efforts pertaining to recycling, re-use and disposal of motor vehicles and vehicle components.

The Vehicle Recycling Development Centre (VRDC) is the technical site of the VRP. The research presented in this paper was conducted at the VRDC as part of the Leaders for Manufacturing Program at the Massachusetts Institute of Technology.

This research was oriented to provide answers to two fundamental questions: "Is there a major threat in the future for the industry recycling automobiles in North America?"; and "Is there something the automobile manufacturers can do to improve the situation?"

Research Process

As explained, when automobiles get retired they can be abandoned or they can be acquired by the recycling industry. If they are to be recycled, they would be collected and brought to dismantlers. Dismantlers remove some parts for reuse or remanufacture, and some materials for recycling. What is left (the hulk) is then compacted and sent to a shredder. This entity processes the cars and recovers most of the metallic materials. The shredding technology is well established. The recovery yields do not vary significantly. Modelling the shredding step, therefore, required the study of established technology and its potential development.

Modelling the dismantling step, in contrast, is a more complex task. Dismantlers perform this activity based on experience and it responds to a variety of factors. Vehicles get into their facilities in very different conditions, the potential value of their parts vary according to complex market dynamics that include inventory levels, exchangeability of parts, demand, and specific cost associated with vehicle dismantling. This is a complex optimisation process.

The author participated in the disassembly research of Mr. Andrew Spicer who developed a Disassembly Modelling Language and a Disassembly Model Analyzer (DMA) [Spicer *et al* 1997].

The DMA is an optimisation program based on a genetic algorithm. This tool is capable of interpreting the complex economic and physical information associated to the disassembly problem of a relatively large product (more than 500 parts). The DMA interprets this information and then returns, among other information, the profit-optimising disassembly plan. The DMA was used to determine the potential impact of several dismantling drivers -- design, prices and costs -- on dismantling practices. The potential impacts were structured in the form of empirical equations using a design of experiments procedure and sensitivity analysis. Ultimately, the dismantling sensitivity analysis led to understanding of how changes in the design and economic environments can affect the overall behaviour of dismantlers.

To collect the data necessary for the DMA, the author worked with the mechanics of the VRDC in dismantling four vehicles using a specially designed time-study.

Extensive research was conducted to build a dynamic model of the automobile recycling industry. Direct interviews and research on reported trends were the primary source of information.

Interviews covered several automakers' operations; development and design, corporate groups in charge of environmental research, divisions responsible for parts specification, marketing and customer behaviour. A group of dismantlers and shredders were visited at their sites and their operations were studied. Other relevant parties were interviewed to understand their economics and the decision making processes of their managers. These included repair shops and landfill companies. As well, several government institutions were approached to understand their policies and get granular information on the car registration and de-registration statistics. Representatives of other industries with high stakes in recycling were interviewed; Aluminum Association, American Iron and Steel Institute, Steel Recycling Institute, and the American Plastics Council. In addition, the opinions of industry experts and consultants were also studied.

Among other aspects of the research, virgin and recycled material prices, automobile composition, flows of vehicles, and cost structures were investigated in official industry statistics and private, company specific financials. This information was gathered, cleaned and used to define parameters and calibrate the model.

The Automobile Recycling Dynamic Model

As mentioned, the two fundamental questions ("Is there a major threat in the future for the automobile recycling industry in North America?"; and "Is there something the automobile manufacturers can do to improve the situation?") are centred around the industry robustness and the automakers ability to increase recycling. It is convenient, however, to list some more granular questions posed about the automobile recycling industry.

"What would happen if suddenly, shredders find themselves operating at a loss because the plastic content of the vehicles is too large?" "What if the dismantlers see their profits diminished because shredders cannot afford to pay them higher prices for the hulks?" "Would Design for Disassembly (DFD), an emerging concept in Environmentally Conscious Design and Manufacturing, save the industry?" Clearly, removal times are also a cost to the industry (labour cost), but "Can we expect DFD savings to offset the additional costs caused by more plastic usage?".

In essence, the ARDM captures the most relevant interactions among parties involved in automobile recycling, with a particular emphasis on how dismantlers and shredders run their businesses. Technical operational elements and financial performance are integral to the model. So is the behaviour of prices and the expectations around them.

In the ARDM the state of the macro-economy (GDP) is an exogenous input that stimulates sales of automobiles. An increase in car sales would result in more cars on the road. This increase in the fleet of cars will eventually result in more cars being retired. Retired cars end up in the dismantlers' hands, who dismantle them and sell them to the shredders as hulks. Hulks are then shredded and ferrous materials are recovered from this process. As more scrap is recovered, more will be offered to the steel industry (increase in scrap supply). This will cause a reduction in the scrap price. Since the price of the scrap and the price of the steel are directly correlated, one can expect the steel price to go down as the scrap price goes down. In principle, a decrease in steel price would stimulate the demand of steel because it becomes a relatively more attractive material. Increases in GDP also increases demand for steel, creating pressure for steel price to increase.

It is important to emphasise the mechanism for the scrap supply to increase as a response to an increase in scrap price. Shredders decide how much they sell as a function of the price they can get for the scrap. If the market is depressed and the scrap price is low, they will accumulate material. Some shredders, for example, explained that they have had up to one year of material accumulated on their property when they thought the scrap price was too low. During the summer of 1995, when the auto scrap price reached a historical high, shredders were selling as fast as they could. It is estimated that during this period they were carrying less than two months of inventory.

Modelling this mechanism involves the use of a *coverage* variable. This variable quantifies how many months of sales of material are desired in inventory and is inversely proportional to the price. In other words, if the price of *product x* increases, the desired *coverage* for *product x* is reduced.

An increase in the price of scrap results in an increase in shredders profit because that is one of their main sources of income. An increase in shredders' profitability allows them to increase the price they are willing to pay for the hulks. This increase in price has three effects; it decreases profits because hulks represent the basic raw material; it increases profit for the dismantlers because hulks are their primary final products; and accordingly, dismantlers decrease their desired inventory coverage for the reason explained above.

People familiar with the dismantlers' practice describe this coverage adjustment in a colourful way: "Walking along a dismantlers' yard allows you to easily see how good the price of hulks is. You just have to look at the fence; if you can see piles of cars above the level of the fence, the price is low. If you do not see any cars above the fence level, the hulk price is high". This accumulation (or de-accumulation process) has a direct effect on the level of cars that are shredded because they will influence the rates at which hulks are transferred to the shredders.

When the profit of dismantlers increase, they are willing to pay more for the junk cars because they want to process more cars and increase their throughput. Again, this causes their profitability to be reduced, but it also causes the rate at which cars are brought to them to increase because owners are more interested in bringing cars to the dismantlers when they know that they will get more money for them Additionally, entrepreneurs currently bringing cars to the dismantlers would increase the radius of their operations, having access to more cars and contributing to the increase in the inflow of cars into the recycling industry.

In addition, two capacity acquisition loops are considered in the model. They capture the effect of competition and over-capacity acquisition in the industry cycle. If shredders become more profitable, the activity becomes more attractive, and more business people would be interested in participating on it. As more investment is devoted to this activity, capacity and fixed costs increase. The effect of an increase in costs is a reduction in profits. The same structural relationship applies to dismantlers. Since the capacity acquisition process involves long delays for ordering and setting up the facilities, one can expect a long-term cycle.

The ARDM is structured in 22 sectors; there is one sector to capture automakers decisions and their execution in the design and production of vehicles. There are two sectors used to model the ageing cars. The ARDM devotes one sector to the physical flow of automobile material since the moment they are de-registered to the point in which the material is reused or disposed in the landfills. The dismantlers' and shredders' operations are modelled in 5 sectors each; capacity, operating rates, expectations and forecasting, financial performance, and basic calculations. There are three independent sectors devoted to the critical prices; scrap price, hulk price, and junk car price. Two input sectors are included; one for the dismantling parameters as defined by the sensitivity analysis using the ADM, and one for general inputs which include exogenous variables and other model parameters including stock initialisation variables.

In the ARDM, the environmental impact of disposing automobiles is traced in one sector, by determining the automobile shredder residue generation, the number of cars being left out of the recycling loop (abandoned cars), and other key environmental indicators.

The ARDM uses a parallel structure (array of variables) to trace five material properties of vehicles: weight, ferrous content, non-ferrous content, plastic content and level of Design for Disassembly (DFD) from the point of sales to the dismantlers' operation. Afterwards, only four properties are evaluated. The property level of DFD has no meaning after the vehicles have been dismantled. The evaluation if these properties is performed in one sector.

There is also a control sector that allows simple definition of initial conditions (equilibrium or historically calibrated) and critical policy decisions. The ARDM was built in Vensim and consists of 823 active equations. The time horizon is 50 years, starting in 1995.

Results
The Automobile Recycling Dynamic Model can be run in two distinct modes: equilibrium and historical conditions. Historical conditions represent the real state of the system at the time of the study. They are far from the equilibrium given that the car sales have increased almost continuously and their composition has changed significantly over time.

<u>Industry Robustness and Structural Deficiency</u>
Starting at historical conditions was necessary to test the robustness of the industry. For the same purpose trends in vehicles' properties (mass, composition and level of Design for Disassembly) were estimated. The base case was created assuming that the vehicle weight will be reduced to 1,000 kilograms and that the plastic component will reach 37% of the total vehicle weight over the next 50 years. Under this scenario, the non-ferrous metal composition would reach 20% of the vehicle weight, while the ferrous fraction would go down from 70% to 43%. This scenario considered a continuously growing economy (annual rate of 3%).

The results of this run are interesting. First, there is a continuous reduction of the fraction of scrap used in the production of steel. The reason is simply that the long delay associated to the use, retirement and recycling of automobiles (approximately 20 years) constrains the supply of scrap relative to the continuous increase in demand for steel driven by the growing economy. This would drive the price of scrap up, however, there is a limit: the price of the virgin material. This scenario shows that the price ceiling (close to $170 per ton) is reached in the next 8 – 10 years.

However, this simulation shows that the prices for hulks and junk cars experience significant reductions after month 300 (year 2020). The main reason is that despite the increases in scrap price, the shredders struggle to sustain their profitability. The reduced levels of metals in the automobiles and the increase in plastics make the value of hulks and junk cars to collapse. Accordingly, abandoned cars accumulate and the recycling of automobiles stops.

The accumulation of abandoned cars gets out of control in the long-run (in 20 or 25 years). This results make an additional and subtle point: the potential collapse would be difficult to foresee if one does not look far enough into the future. Changes in automobile composition and design will take a long time before they manifest themselves. In this context, the fact that the system seams to operate well at the near future may be misinterpreted as a signal that the system will be robust indefinitely.

Of course, this result is not a prediction. The whole purpose of this work is to help in the understanding the system in such a way that related parties, and specifically automobile manufacturers, act to reduce the environmental impact of disposing automobiles. Thus, concluding that in the future the Automobile Recycling Industry in North America has low possibilities to exist under its current structure, should be interpreted as saying that the structure has to change for the industry to survive, as opposed to saying that the industry is facing an imminent and unavoidable collapse.

In other words, the purely economic-driven structure does not seem to be able to manage the simple extrapolation of historical trends in vehicle weight and composition. Nor does it seem capable of dealing with plausible increases in prices defined outside the system, such as labour and landfill costs, or non-ferrous metals and plastic prices.

There is one fundamental reason behind these results: there is a structural deficiency in the system that does not take into consideration environmental objectives properly.

Structurally, self-maximising decision rules tend to reflect additional costs faster than incremental savings when setting prices. For example, in one scenario the plastic content was increased by 20% and sustained at the higher level throughout the simulation. As a result, dismantlers' profits were reduced by 2.5%. However, when the alternative scenario was run and plastics were reduced by 20%, an increase of profits of 12% was observed.

In contrast, the effect on ASR generation is almost symmetrical: total cumulative mass sent to the landfills in the first scenario increased by 10% while in the second case went down by 10.5%.

When comparing the effect Design for Disassembly, the same type of results are observed. Significant increases in DFD result in 42% more profits to dismantlers. When level of DFD is significantly reduced profits go down only 15%.

These results make one point clear: dismantlers "own" the junk cars after acquiring them. Accordingly, they perform on them what is optimum for their monetary objectives: suppose, for instance, that the adoption of certain automobile manufactures' *policy x* is known to cause dismantlers additional disassembly costs. It might be tempting to think that an increase in DFD level would offset the incremental costs and result in the same level of dismantling for material recovery as before the adoption of *policy x*.

Nothing is further from the truth. There is no mechanism that relates one-to-one the level of dismantling to the level of DFD. In all cases, the material recovery level will be defined in terms of the disassembly plan that produces maximum profits. In other words, it is possible that the adoption of *policy x* accompanied by an increase in DFD results in lower level of disassembly, in lower junk car price, and in an improved dismantlers' profit. Dismantlers can reflect the incremental cost of *policy x* in the junk car price and capitalise a good portion of the benefits of DFD.

In the scenario where the use of plastics was increased by 20% the dismantlers' profits were not significantly reduced. However, it has been explained that plastic usage represents a pure cost to the system. Thus, one can ask "Who paid the incremental cost?" The answer is we all did: there is a 10% increase in material landfilled. In the model, increasing amounts of ASR do not result in increasing tipping fees. Therefore, we all paid the price of the increase in plastic usage partially by accepting more ASR in our landfills.

The second element of the environmental costs is number of cars abandoned. In the case of an increment of the plastic usage, this stock increases by almost 24%. Thus, we also paid the price of an increased usage of plastics by accepting more cars to sit and wait to be processed.

The purely economically driven industry, as its own name suggests, has no environmental considerations. People recycle cars and recover materials from this process because they make money doing it. Pollution is an economic externality, of course, and these results illustrate the "tragedy of the commons": the fluff sent to the landfill, or the number of cars abandoned are economic externalities. Everybody is worse-off if they increase, but no one is better-off by individually trying to prevent them.

Influence of Automobile Manufacturers in the Recycling Industry

Interestingly, in the scenario where the level of plastic usage went up, the amount of material dismantled increased by almost 47%. This is a counterintuitive result.

The reason behind this phenomenon is that as dismantlers perceive their profit reducing, they undertake more recycling, going into deeper levels of the cars' structure. They do this seeking to increase their recycling revenue. They try to offset, at least partially, the negative effects of more plastic.

This result has to be taken with a grain of salt. It is tempting to jump to the conclusion that policies oriented towards reducing dismantlers' profit might be beneficial from the environmental perspective. Although some of these policies might indeed increase the level of dismantling, they would most probably cause the junk car price to go down with the corresponding increase in the number of cars abandoned.

On a different front, DFD is an activity that comes at some cost. Automobile manufacturers would need to balance the benefits –as explained, very modest-- of improving the level Design for Disassembly against its cost. However, as discussed the dismantlers benefit from this activity, because they are in the best position to capitalise from lower costs of disassembly.

One can argue that consumers benefit as well from DFD, since they would receive, after all, more money for their junk cars. Although this is true, we should examine carefully the intention of DFD. Automobile manufacturers would presumably incorporate higher levels of DFD not to pass onto consumers an additional monetary benefit, but rather to increase the recycling of cars.

One can ask "Why should dismantlers benefit form an increase in DFD at a cost to the automobile manufacturers?", "What if they were asked to realise the *same* profit and recycle *more*?"

Sensitivity runs where the car weight and the material composition were changed indicate that these variables, within reasonable ranges, are enough to either ensure the industry survival, or the industry collapse. However, this is not new. Historical trends in car weight and material composition were precisely the sources of the most sombre questions associated with the future of the industry before this work was undertaken.

Besides, car weight and material composition are defined based on many other --and likely more important -- performance characteristics. Fuel efficiency, driving performance and cost are among them.

What is new is that the model allows the VRDC and the automobile manufacturers to evaluate the possible effects of alternative policies. The ARDM may help them understand the long delays in the system and might stimulate thinking in terms of managing, today, the possible future consequences of their decisions.

Conclusions

Any dynamic model can be used for several purposes. Although the original intention defines a lot of what the model includes, it is frequently the case that upon completion of the model, it represents a major source of additional learning. This work includes only the initial manipulation of scenarios and learning that the ARDM can generate.

More importantly than forecasting, the model can be the basis for hypothesis testing and for discussion. The environmental impact of disposing durable goods is not an area with which companies are familiar. Neither is the scientific community an expert on this field. From the definition of what is recyclable to the implementation of strategies, there is a lot of miscommunication that prevents constructive dialogue. The ARDM, because it is explicit in every aspect, can bring people together and promote constructive discussion. Nothing will satisfy the author more than knowing that industry participants disagree with some of the model's assumptions and simplifications, and accordingly, they would work on restructuring and expanding the model.

By running the model in a variety of conditions the author concluded that: 1) The automobile recycling industry in North America is not particularly robust, 2) Simple continuation of vehicle mass reductions and increases in the usage of plastics may cause an irreparable damage to the industry, 3) A significant influence on the viability of the industry is in the hands of the automakers, 4) The effects of automakers' decisions are difficult to evaluate with traditional analytical tools given the long term delays and the presence of feedback in the system, and 5) Improvements in recycling will be difficult to achieve by simply changing design characteristics in automobiles: parties will tend to capture only the economic benefits of changes and actual recycling would not necessarily increase.

What type of additions to the economic-driven structure can one think to improve both the economic viability of the industry and the environmental performance? This is precisely the most interesting area for expansion of this research. It may involve consideration of government intervention, and evaluation of alternative structures.

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