Using System Dynamics to
Create Durable Business Strategy:
US Air Conditioning Industry Case Study

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Abstract

This paper describes the use of system dynamic modeling at Refrigeration Sales Corporation (RSC) to understand United States air conditioning industry dynamics and to determine advantageous business policy changes. The business context, model designs, and the resulting policies and outcomes are described. The described system dynamics models extend Bass diffusion to include replacement sales of a durable good. Within this context, the relatively long useful life of a central air conditioning unit causes a significant contraction in the industry sales rate prior to reaching sustainable replacement sales. Anticipating the contraction and changing company policy accordingly gave RSC a competitive advantage by being prepared to take advantage of the industry changes. This paper adds to the system dynamics body of knowledge by documenting a successful modification and application of pre-existing model structures within the context of an important and valuable durable goods industry. Insights presented in this paper may be applicable to other durable goods industries.

Introduction

Refrigeration Sales Corporation is a privately owned fourth generation family business that has a long history of serving the heating, ventilating, air conditioning, and refrigeration (HVACR) markets in Ohio and surrounding states. In the year 2001, RSC's management suspected that the underlying HVACR industry was undergoing a significant change. Average annual compounded industry growth (year-over-year sales increases of all brands through all competitors) had begun to slow. After more than three decades of planning for strong industry growth, RSC management strongly suspected that their future success would require a confident forecast of changes in the future industry opportunity.

A lack of a consensus forecast among industry insiders and the sensitivity of RSC's profitability to revenue growth created uncertainty about RSC's long-term strategic investments and drove RSC management to seek a better understanding of what was causing the apparent industry weakness. In addition, the uncertainty had developed as the business was changing leadership from the third to a fourth family generation creating additional stress on the firm. The incoming president was an HVACR outsider with computer industry and general business experience. He was also familiar with

system dynamics[1] as a methodology to investigate and describe feedback rich systems. This paper describes the use of system dynamics by RSC management to create a confident understanding of the changing HVACR industry and the RSC business policies that resulted. Actual industry results through 2010 are also presented. A case study documenting the situation at RSC leading up to the year 2000 has been written and is currently being used to teach strategy at the Fuqua School of Business at Duke University and the Keenan-Flagler School of Business at the University of North Carolina in Chapel Hill.

RSC Present and Past

Refrigeration Sales Corporation is a wholesaler of heating, ventilating, air conditioning, and refrigeration (HVACR) equipment, parts, and supplies. RSC purchases finished goods from over a hundred product manufacturers located throughout the world and sells to thousands of small and privately owned mechanical contracting companies that provide the installation and service of residential, commercial, and industrial HVACR systems. Typical product applications range from home heating and cooling to refrigerated grocery store displays. RSC earns a middleman margin by providing local product availability, customer account credit, 24 hour product and application support, and a variety of technical, sales, and business training services. RSC does not currently manufacture products or provide installation services.

RSC was founded in 1923 as The Kelvinator Cleveland Company, a retail store for Kelvinator brand mechanical iceboxes (an early refrigerator). The term "mechanical icebox" describes an icebox that has been converted to include a heat transfer technology that uses electricity to compress and expand a refrigerant gas in a continuous closed loop (thus eliminating the need for ice). According to RSC company records, in 1923, a "well-equipped" mechanical icebox sold for $750 (equivalent to about $10,000 in 2010). While the cost to manufacture, product efficiency, and component technologies have changed since 1923, modern air conditioning and refrigeration systems sold today rely on the same basic mechanical refrigeration technology of compressing and expanding a refrigerant gas.

A Critical Forecast

In 2001 a new company President was eager to make a positive contribution to RSC's future success. Company management believed that recent US air conditioning industry unit sales data[2] suggested a slow-down in unit sales growth (see figure 1 below). Actual unit sales history through 2001 is shown (black) with a smoothed trend line drawn by RSC management (blue). In addition, RSC management had access to proprietary data suggesting industry unit sales within RSC's territories (versus the entire

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[1] MIT/YPO seminar Jan 2001; MIT executive education Jun 2003; WPI Mater of Science in SD awarded May 2011.

[2] US air conditioning industry unit sales data include compressor bearing split system condensing units, AC, HP, and Ductless. Window AC units are not included. While this data represents about 30% of RSC sales, it was thought to be an excellent proxy for the overall business.

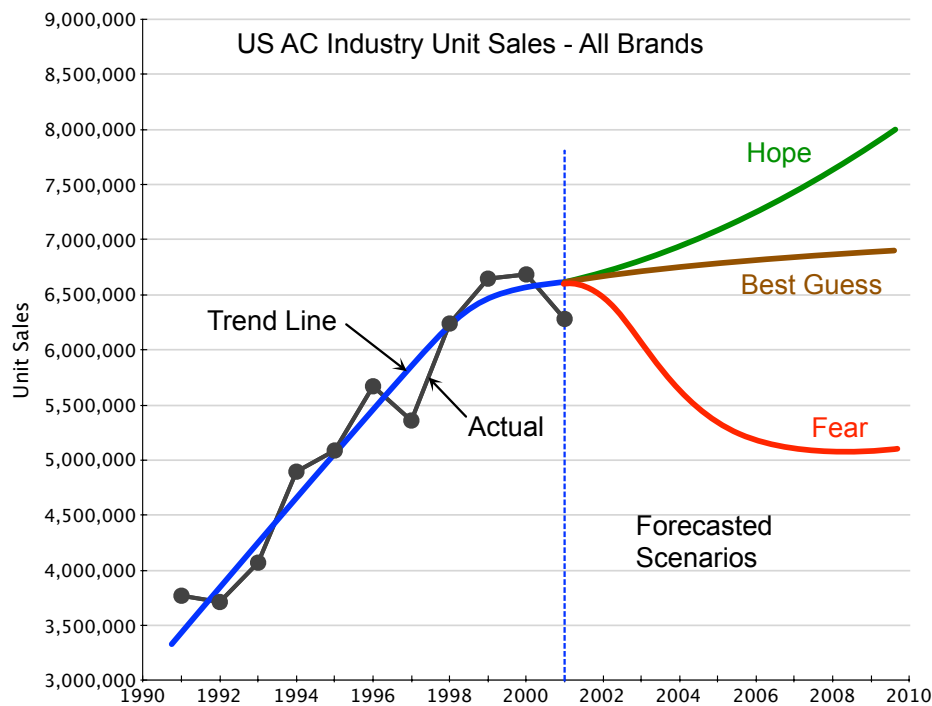US shown here) had begun a slowing trend in 1998, three years earlier than the national numbers.

Figure 1: 2001 US AC Industry Reference Mode[3]

An accurate forecast of the AC industry was critical for several reasons. As a wholesaler, RSC profits are extremely sensitive to changes in unit sales volume. Employee expense and facilities expense, both semi-fixed costs, make up 80% of RSC's overall budget (after paying for finished goods). Making a wholesale profit is accomplished when unit sales per employee and per square foot of warehouse are maximized. However, HVACR is a highly seasonal (weather dependent) business and the overall unit volume fluctuates considerably from year to year. While people and facility efficiency is critical, it must be balanced with extra capacity to capture an industry upswing.

An increase in industry sales that is not captured during an upswing, will go to a competitor and result in a lost customer who will be difficult and expensive to re-capture. In addition, employee expenses and vehicle expenses had been rising quickly due to increases in insurance premiums (primarily health care) and increasing fuel costs, while corresponding sales revenue had begun to flatten. A quick calculation convinced RSC management that a continued slowing of industry unit sales growth combined with increasing expenses would result in profit losses in the near future.

Initial forecast estimates were obtained by interviewing RSC customers and suppliers. RSC customers generally felt that demand was experiencing a "temporary

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[3] Air Conditioning, Heating, and Refrigeration Institute, 2011, "Central Air Conditioners and Air-Source Heat Pumps Historical Data".

lull" similar to those experienced in the past, but that healthy industry growth similar to past years would return. While customer optimism was strong, RSC customers were in agreement that 80% or more of their business was replacement of existing AC units, or installation of AC units in new construction. Jobs installing AC into existing homes previously without AC were a small and shrinking part of their business.

RSC suppliers (including brands such as Carrier, Bryant, Heil, Tempstar, Copeland, and Manitowoc) were also generally optimistic, although more cautious then RSC customers about future industry growth rates. Their forecasting models recognized that adoption of AC into existing homes was mostly completed. However, a healthy new construction market was projected to keep the installed base of AC equipment growing. In addition, the energy efficiency of new AC equipment was increasing and giving some homeowners a reason to replace an otherwise operating AC unit to take advantage of decreased operating costs. As a result, robust AC replacement sales were forecasted. The combination of RSC customer and supplier forecasts (weighted towards the more conservative supplier version) became the RSC "hope" forecast scenario (green) shown in figure 1.

RSC management developed an independent industry forecast based on the idea that no product sales grow forever. Using this mental model, the ending of adoption sales (confirmed by customers) meant industry sales would be approaching a sustainable replacement rate. In this forecast, industry growth from adoption has been slowing and will soon disappear, making future AC industry growth (assuming a constant replacement rate) equal to growth in the installed base of AC units.

Estimating growth in the installed AC base using expected rates of new construction (as described by suppliers) seemed questionable to RSC management. While new construction was healthy within RSC's territory, the overall population within the territory was estimated to be growing at a very slow rate (nearly 0%) for the foreseeable future. To reconcile healthy new home construction with a flat population[4], it was decided that for every new home constructed, an old home was being demolished. Further, it was decided that the probability of a new home being built with AC installed was roughly equivalent to the probability that the old home being demolished had AC installed. This new mental model suggested that population growth and not new home construction would be the primary driver of growth in the installed base of AC units. Low population growth implied slow growth in the installed base of AC units. This reasoning became the basis for the RSC "best guess" forecast scenario (brown) shown in figure 1.

In addition to the two forecast scenarios above, a third scenario was proposed by a member of RSC's outside Board of Advisors. Figure 2 shows the Booz-Allen-Hamilton chart provided by this new Board member and suggesting that industry sales volumes decline sometime after profit margins begin to decline. Interviews with HVACR wholesale peers around the US convinced RSC management that industry profit margins were under pressure and had indeed begun a gradual decline.

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[4] US census data shows that the number of people per housing unit is relatively stable and thus should not affect the analysis.

FIGURE 2-1. Product Life Cycle.
Source: Management of New Products (Chicago: Booz, Allen & Hamilton, Inc., 1968), p. 4.
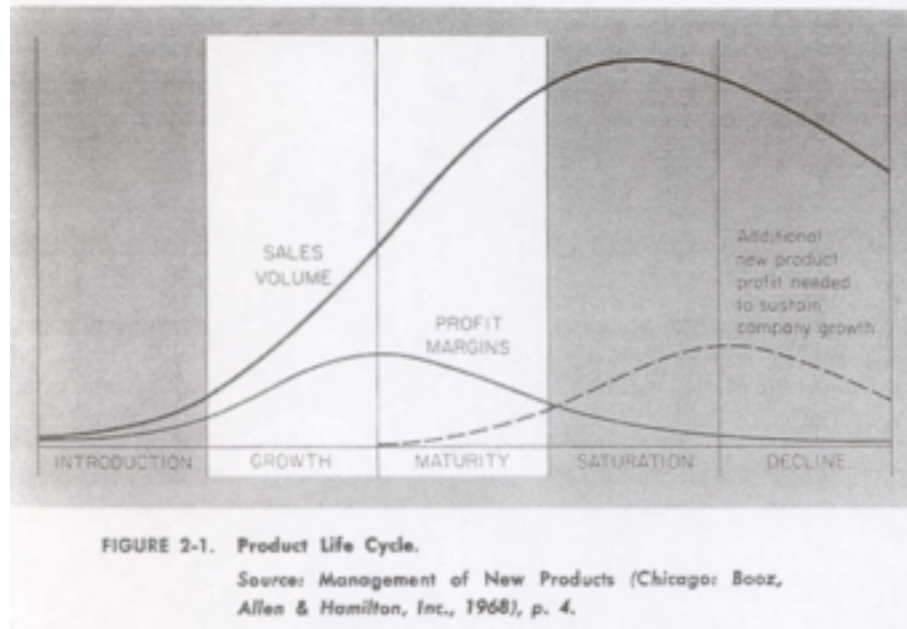
**Figure 2: Booz-Allen-Hamilton chart showing
potential for industry sales decline**

Based on the chart in figure 2 as well as the experience of RSC's newest Board member, RSC management proposed a third forecast scenario that became the basis for the RSC "fear" scenario (red) shown in figure 1. The "fear" scenario requires the industry sales rate to peak and then contract before reaching a sustainable replacement sales rate. RSC management decided to recognize the "fear" scenario despite the fact that they did not have any specific reasoning to support this industry dynamic, other than the Booz-Allen-Hamilton chart. (The "fear" scenario was not intended to predict a new product or technology substitution effect. While several different heat transfer technologies exist, the widely-used technology based on compressing and expanding a gas is expected to be the preferred technology for the foreseeable future.)

Many Priorities and Industry Norms

While the US AC industry forecast was critical to creating an overall strategic direction for RSC, there were many immediate business priorities that required management's attention. During the time required to perform interviews and develop forecast scenarios, RSC management focused on immediate priorities including: upgrading RSC's employee policies, developing an improved performance management system, acting on poor employee performance, centralizing and improving the purchasing function, identifying and removing unprofitable product lines, implementing warehouse bar-coding for improved inventory control, identifying and improving inefficient workflows, recruiting Board members from outside the family and HVACR industry, and creating shareholder buy-out opportunities to consolidate company ownership. These initiatives were believed to be prudent regardless of which forecast scenario was correct.

RSC management believed that the "hope" scenario was the least likely of the three scenarios. However, the prospect of slow (or negative) industry growth for a sustained period of time was unprecedented in the HVACR industry. Based on this possibility, RSC management determined other possible actions including: consolidating warehouse space, reducing the size of the workforce, and tightening the customer credit policy. These additional priorities represent the majority of RSC expenses. They also proved to be much harder to implement because of existing industry norms based on decades of healthy industry growth. Because of sustained industry growth, industry competitors had grown accustomed to focusing on resources required to grow their own businesses and providing the capital required to grow their customers' businesses. Having extra warehouse space to grow into was a rule of thumb, which made shareholder-owned facilities and signing long-term leases a preferred way of doing business. Consolidating warehouse facilities was discouraged by RSC suppliers and customers and was considered a short-sighted mistake in the face of a temporary downturn. Prematurely selling unused industrial properties at a loss or paying lease obligations on vacated warehouse space would have a significant negative financial impact to RSC.

The HVACR industry is highly technical. Employees with experience and skills in HVACR are difficult to find and recruit. During decades of expansion, most highly qualified employees were trained in-house and were retained by the same company for their career. While this practice created a loyal and skilled workforce during years of expansion, it also created a strong belief that reducing the size of a company's workforce was another short-sighted mistake.

The growth of the HVACR industry required lots of financial capital. Because the majority of the firms in the industry are small and privately-held, the availability of bank capital is greatly restricted. Banks are either unwilling, or the process of borrowing from a bank is too burdensome for the small business owner. The resulting financial capital gap was filled by HVACR wholesale companies that were larger and able to secure bank financing based on the significant inventories and accounts receivable carried on their balance sheets. As a result, RSC management provides banking services to their customers who purchase on account. The possibility of a "fear" scenario indicates an industry consolidation and financial distress, likely putting many small mechanical contracting firms out of business. RSC management did not want to be left holding worthless unsecured promises to pay on account. Even a 10% industry sales consolidation would be a far greater loss than RSC's normal annual accounts receivable write-offs of about 0.2% of sales. But credit from wholesalers had been historically easy to get. A significant tightening of RSC's credit policy would put the company at a significant competitive disadvantage.

All of these additional priorities were perceived by RSC management to be significant risks. Successfully implementing any of these additional priorities would require a consistent focus for multiple years. A return to industry growth would require additional space, employees, and customer credit. However, an industry contraction could result in years of profit losses if facilities, employees, and customer credit were

not reduced in advance of the industry decline. The arguments for each of the forecast scenarios seemed plausible. The perceived complexity of the industry and the possibility of an unprecedented decline demanded a more confident forecast. From the perspective of shareholders uninvolved with business operations, these uncertainties and difficulties occurred at the same time that the new RSC president began making changes in the business. This added additional pressure on RSC management to "keep things the way they are."

An Initial System Dynamics Model of the US AC Industry

In 2001 while attending a week-long business seminar at MIT, the RSC president was introduced to system dynamics modeling as a way to describe and test dynamic situations. The initial exposure lead to additional study of existing system dynamics models of diffusion. An example Bass diffusion model (Sterman, 2000) was modified to represent the adoption and diffusion of AC units in the United States. AC replacement sales were added to the model shown in figure 3 below.
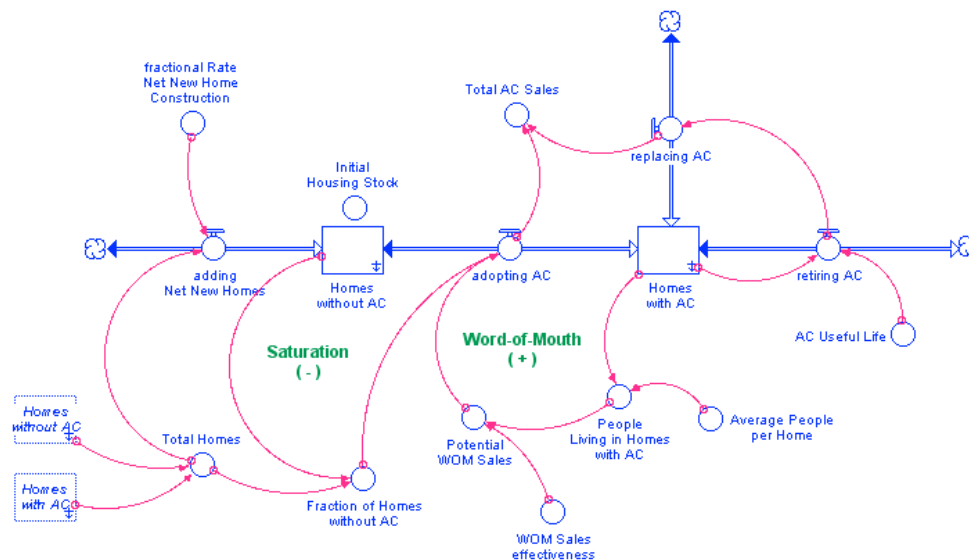

Figure 3: Initial Model of AC Diffusion with Replacement

This initial model contains two stocks: Homes without AC and Homes with AC. At the core of the model, an initial housing stock (without AC) adopt AC through a positive feedback word-of-mouth (WOM) process until the diminishing base of homes without AC limits the adoption process as market saturation occurs. The stock of homes with AC is seeded with a small fraction of the initial housing base to avoid adding advertising mechanisms not believed to be critical to the behavior of this model. Net new homes (total home additions minus home demolitions) flow into the stock of homes without AC. After a useful life, AC units flow out from homes with AC as they are retired. The flow of retiring AC units drives a one-for-one flow of replacement AC unit sales back into the stock of homes with AC. Total annual AC unit sales are equal to the sum of adopting and replacing AC unit sales.

The simulation behavior of this model is shown in figure 4. As expected, the stock of homes without AC (blue, top chart in figure 4) drains into the stock of homes with AC (red, top chart in figure 4) through an adoption flow. The adoption flow (blue, bottom chart in figure 4) gains momentum slowly as early AC adopters are few, but eventually accelerates and then decelerates to a peak value as the market begins to saturate. Because there is a constant inflow of net new homes without AC, this stock never goes to zero, the adoption flow never goes to zero, and the stock of homes with AC continues to grow.
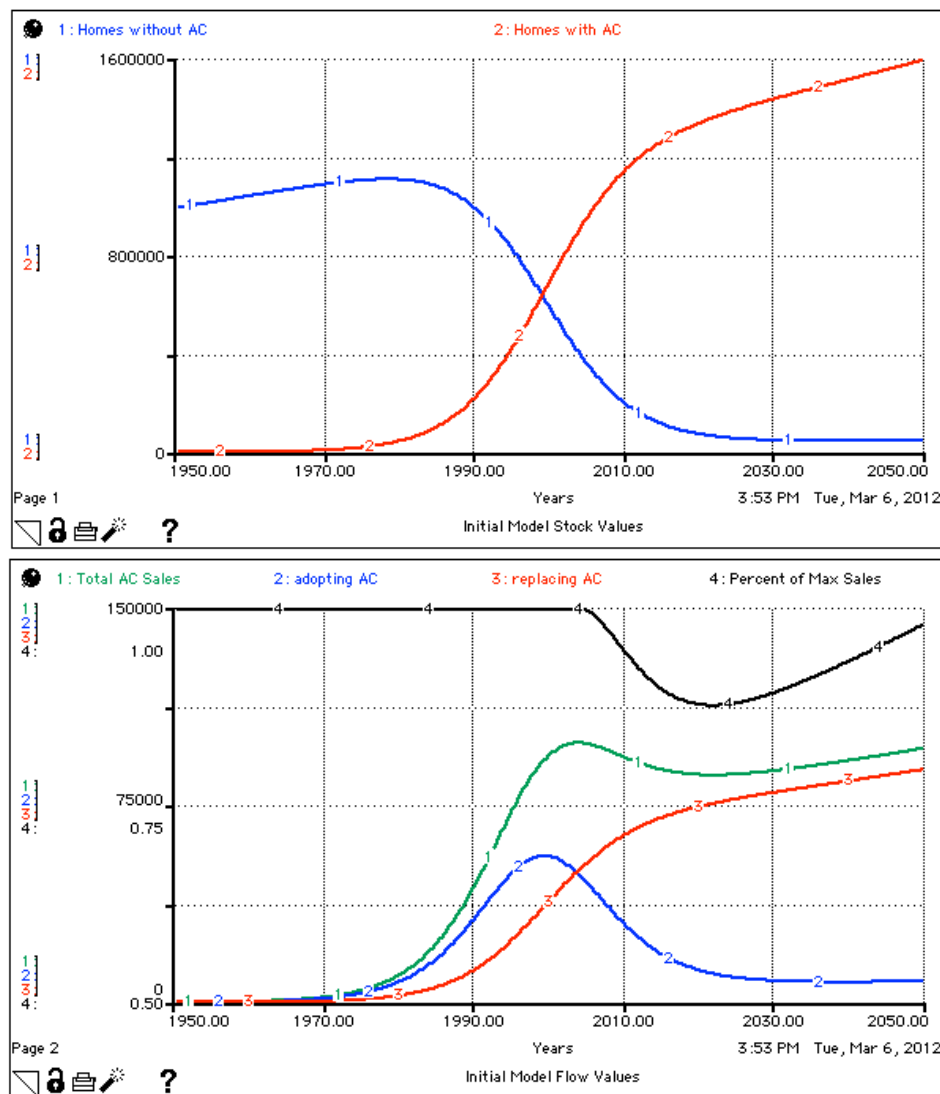

Figure 4: Initial Model- Stock and Flow Simulation Values (AC useful life of 18 yrs)

The flow of replacement AC sales (red, bottom chart in figure 4) follows the size of the installed base of homes with AC. The useful life of an AC unit is relatively long (a durable good) making the replacement flow generated by the installed base smaller than it otherwise would be for a typical non-durable good. The surprising result (to RSC management at the time) is that the replacement sales flow is sufficiently small

compared to the adoption sales flow that the total sales flow (green) contracts before it reaches its sustainable replacement sales rate (Bass, 1969). The magnitude of the total AC sales contraction from its peak value (black) was significant in early simulation results. This simulation result grabbed the attention of RSC management and provided a plausible explanation for the "fear" forecast scenario.

While this initial model has many weaknesses, its primary strength is its parameter simplicity. With only a few parameters to think about, RSC management was able to grasp the importance of AC useful life (product durability) when determining the likely behavior of future industry sales. The results of four simulations of total annual AC unit sales with different values of the parameter "AC useful life" (8, 12, 16, and 20 years) are shown in figure 5 below.
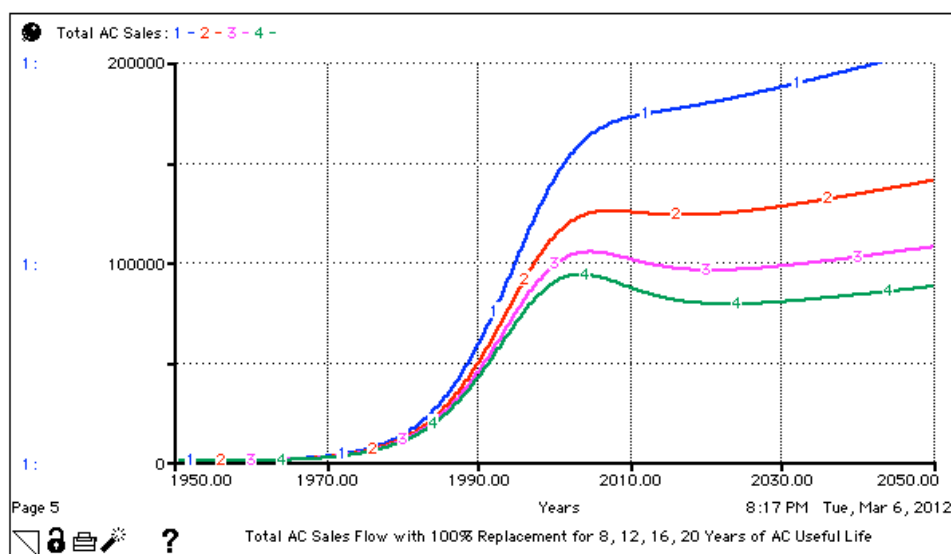

**Figure 5: Initial Model- Total Annual Sales Simulation Comparison
(AC useful life of 8, 12, 16, and 20 years)**

As can be seen in figure 5, changing the length of AC useful life has a big impact on the size of the total AC sales rate and the degree to which the total AC sales rate must contract before reaching the sustainable replacement sales rate. The two components of total AC sales are adoption sales and replacement sales. Assuming that WOM effectiveness does not change and that every retired AC unit is replaced, the adoption sales flow does not change when AC useful life is changed. This means that the change in total AC sales is entirely composed of the change in the replacement AC sales flow.

For a given AC installed base, a longer AC useful life means later failure and less annual replacements, whereas a shorter AC useful life means sooner failure and more annual replacements. The magnitude of the replacement sales rate compared to the (unchanging) adoption sales rate determines how much the total annual sales must contract before reaching the sustainable replacement sales rate. An 8 year AC useful life requires 2.5 times the annual replacement sales that a 20 year AC useful life does. As a result, the 8 year useful life total sales flow (blue) is much bigger and does not

experience a contraction, whereas the 20 year useful life total sales flow (green) is not only much smaller, but also contracts (by 16% from its maximum rate) before reaching the sustainable replacement rate. This parameter sensitivity analysis implies that any AC useful life above approximately 15 years requires a significant (10%) contraction in total annual AC unit sales.

The other model parameters have a less dramatic effect on the total annual AC sales rate. The fractional rate of net new home construction controls the growth rate of available AC installation opportunities. During the adoption phase, growth in the installed base of AC happens rapidly due to AC adoption. It is only after AC adoption has saturated that the growth in the AC installed base is limited by growth in AC installation opportunities (homes). Thus, the fractional rate of net new home construction primarily determines growth in the sustainable replacement sales rate.

At this stage of modeling, RSC management did not make an attempt to explicitly model the US housing stock with separate construction and demolition flow rates. The mental model being used by RSC management was that new home construction is mostly replacing old home demolition. Thus, the fractional net new home construction rate (new construction minus demolition) is the parameter included in this model. Further, it was assumed that the number of people per home was constant during the model simulation period implying that the fractional net new home construction rate could be estimated using the historical and expected fractional net US population growth.

Using the model as formulated, no reasonable value of fractional net new homes (fractional net population growth) can produce annual sales increases like those during the adoption phase. This reasoning implies that if adoption sales are nearly complete (as determined by various customer interviews), then rapid annual sales growth has ended and that the "hope" forecast scenario is not likely to happen. However, the tail-end of the "best guess" and "fear" scenarios were likely to show some slow growth.

The WOM sales effectiveness (and number of people per home) determines the rate at which the adoption flow accelerates before beginning to saturate. The greater the WOM sales effectiveness, the faster adoption sales accelerate causing the market to saturate and the sooner total annual sales must plateau or contract to the sustainable replacement sales rate. Varying the WOM sales effectiveness does not change the fundamental behavior of this model, but it does move the timing of the sales peak. WOM sales effectiveness was modified in an effort to match the beginning of peak sales with the reference mode pattern shown in blue in figure 1.

Finally, after several months of working with this model, it was decided that two significant modeling flaws needed to be addressed. First, there is a problem with unit consistency. Net new homes flow into the aging chain of homes, but defunct AC units flow out. It is unclear if the stocks in this model are homes or AC units (it may not be reasonable to assume that every home has one and only one AC unit). The model does produce a useful behavior over time, but it does not "fit" the available AC unit sales reference mode shown in figure 1. Second, RSC management was able to gain

considerable insight into what might cause an industry sales contraction as suggested by a Board member, but the timing of the contraction and the rate at which it occurs in the model are suspect. RSC management believed that WOM sales effectiveness was comprised of more components (such as AC affordability) and that WOM sales effectiveness may not be constant throughout the simulation time period. A model containing these modifications is described in a later section of this paper.

RSC Policy Actions and Updated US AC Industry Sales

During the period from 2001 through 2010, the RSC management team used all available sources of information, including the system dynamics modeling exercises described in this paper, to determine new business policies that would position RSC for a successful future. The new RSC president was being motivated by a desire to preserve and grow shareholder wealth for future owners, but also by a fear of having the business fail on his watch. If the fundamental behavior pattern of the US AC industry was changing significantly, he knew that RSC management had to understand the causes and create business policy that anticipated important industry changes. The decision was made to forecast a modest contraction in the available AC industry sales and base all future policy decisions on this forecast.

Adopting a forecast for industry sales contraction meant making more aggressive policy changes than had been anticipated before the system dynamics modeling exercises. Many of the resulting policy changes were controversial and contrary to prevailing industry wisdom. To put the resulting policy changes into context, an updated US AC industry sales chart is presented in figure 6 below. This chart is identical to RSC management's original reference mode (figure 1), with the addition of actual US AC industry units sold from 2002 through 2010.

Actual industry sales unfolded dramatically. The 2002 and 2003 sales years supported the realization of either a "hope" or "best guess" scenario with no big change in sales rate. However, record industry sales in 2004 and 2005 exceeded the most optimistic "hope" scenario. The 2005 sales year was the last year that manufacturers were allowed to make 10 SEER condensing units. In 2006, new federal EPA guidelines mandated that the minimum allowable AC unit efficiency to be manufactured was 13 SEER. This represented a 30% increase in efficiency, but also a large increase product materials (aluminum and copper) and thus a corresponding increase in product cost.
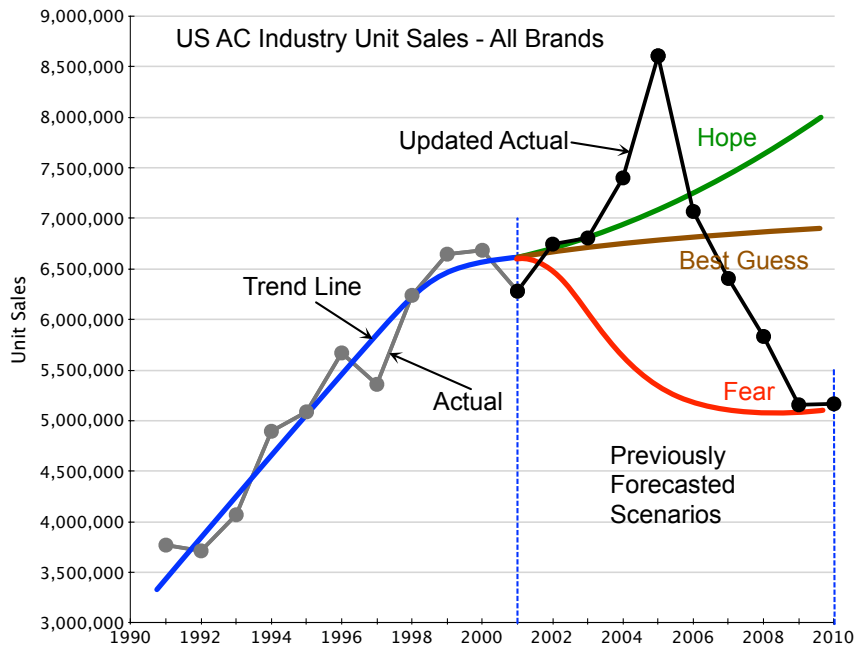
Figure 6: 2001 US AC Industry Reference Mode Updated with 2010 Actuals[5]

It is widely believed that the record sales achieved in 2005 were the result of customers buying ahead to beat the price increase. While not all customers could plan or afford to buy ahead, many did (e.g. a property management company would budget additional AC replacements to beat the price increase). Even taking these extra sales into consideration, industry sales in 2004 and 2005 seemed to support the "hope" scenario. Industry sales in 2006, brought the overall sales rate back to the level of both the "hope" and "best guess" scenarios, although many believed that 2006 sales levels were depressed from what they could have been because of the prior year's buy-ahead activities.

After the record industry sales of 2005, AC industry insiders expected a correction (especially considering the many unfavorable economic factors occurring at the time), but few, besides RSC management, had a ready explanation for four straight years of unprecedented decline. At the end of 2009, US AC industry sales rates had contracted 40% from their peak value and were equal to the historical sales rate of 1995 (fourteen years prior). If the industry sales rate did not improve, the AC manufacturing and sales channel would be 30% to 40% over the capacity required by demand.

Because of their careful forecasting work, RSC management held to the policies supporting an industry sales contraction throughout this period. This was especially difficult to maintain in the face of unexpectedly strong sales rates through 2005. Dividing RSC policy changes into two time periods, they can be summarized as follows:

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[5] Air Conditioning, Heating, and Refrigeration Institute, 2011, "Central Air Conditioners and Air-Source Heat Pumps Historical Data".

RSC Policy Implementations: 2001 though 2005

• Reduce the RSC employee base by 15% (people) by implementing a one-time workforce reduction and holding this employee count for the foreseeable future;

• Reduce the RSC facility space by 30% (square feet) by breaking long-term leases and selling unproductive properties;

• Implement job descriptions and performance goals for all employees (including the president); measure and act on poor performance;

• Implement purchasing and warehouse technologies to increase inventory accuracy and reduce inventory levels while improving order fill-rate;

• Retain cash by reducing inventory, eliminating shareholder entitlements, and cutting the shareholder dividend.

The first five years from 2001 through 2005 were the most challenging years for RSC management. The interviews and strategic modeling work leading to the policies listed above were critical to building the confidence required to make such visible and unprecedented capacity reductions. These changes were controversial from the perspective of RSC's employees, customers, and suppliers. This was especially true as industry sales climbed to a record level in 2005. In fact, RSC contraction policy resulted in missed sales opportunity during the unanticipated record sales of 2005 as RSC capacity could not keep up during the busy summer selling season. In hind-sight, however, RSC's reduced expenses, increased productivity, and retained cash were critical to taking advantage of the coming five years of industry sales declines.

RSC Policy Implementations: 2006 though 2010

• Tighten customer credit reducing receivables days sales outstanding by ten days;

• Diversify product offering by adding new product lines;

• Recruit the competitor's best sales talent;

• Open and acquire new wholesale branch locations in new sales territories.

The second five years from 2006 through 2010 provided RSC management an opportunity to go deeper into their understanding of the AC industry dynamics. As a result of prior policy actions, RSC management had marshaled the required resources to take advantage of the uncertainty developing as the industry contracted. Diversifying into related product and customer segments provided a way to utilize existing company resources to grow sales and share of the contracting market. In response to the contracting market, RSC competitors were slashing expenses and disenfranchising their employee base making their best employees open to new opportunities. Recruiting a competitor's best sales person was a double win as RSC gained and the competitor lost. Industry suppliers were desperate for sales increases, making previously unavailable product lines available to RSC. These actions were available to RSC

specifically because the industry was in decline and RSC was positioned with the resources to invest. Finally, RSC's investments in employee performance, purchasing, and warehousing accuracy made opening and acquiring new sales locations in new territories profitable more quickly.

During the period from 2000 through 2010, while US AC industry sales contracted by 23% (data presented in this paper) and AC industry sales in RSC served territories contracted by over 30%, RSC annual revenues grew by 25% and RSC customer sales locations grew by 30%. Although 25% revenue growth over ten years is equivalent to a modest 2.5% compounded annual growth rate, RSC management was proud of their accomplishments given the unprecedented industry sales contraction and they are confident that the Company is well positioned for accelerated future growth.

An Updated System Dynamics Model of the US AC Industry

After creating an initial model of the industry that explains a possible cause for a contraction in US AC industry sales, RSC management set out to improve the model, to create unit consistency, and to "fit" the model behavior to known US AC industry sales data. Unit consistency within the model was achieved by separating housing and AC unit installations into two separate aging chains. The housing aging chain is shown in figure 7 below.
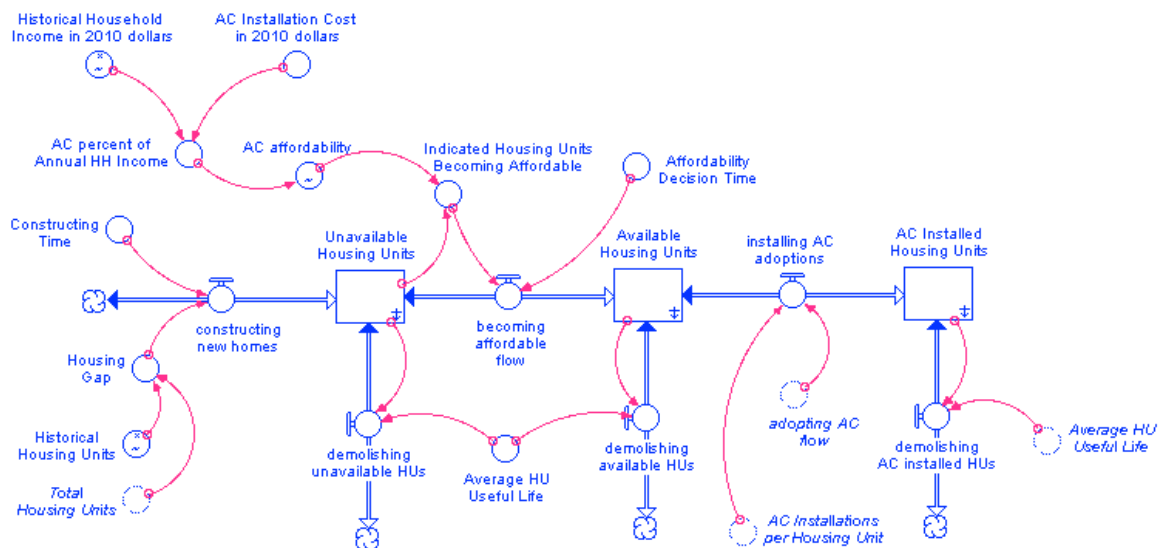

Figure 7: Updated Model - Housing Aging Chain

Houses are initially unavailable to have air conditioning installed because the homeowners can not afford the relatively new and expensive AC technology. As the expense of central AC (held constant in 2010 dollars in the model) becomes a smaller percentage of household income[6] (expressed in 2010 dollars), AC affordability increases. The more affordable AC becomes, the more housing units become available

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[6] US Census data (http://www.census.gov/hhes/www/income/data/historical/household/)

for central AC installation. Central AC is installed in available housing units as determined by the advertising and word of mouth dynamics of the AC unit aging chain portion of the model (shown next). Housing units are constructed at a rate sufficient to keep the total model housing stock equal to known historical values[7] (with a steady state error). Housing units are assumed to have a useful life of 75 years. Housing unit stocks are initialized to zero with the exception of unavailable housing units which are initialized to the known historical value.

Air conditioning installations do not begin until there is a potential customer (Warren 2008). Potential customers grow as AC becomes more affordable and the stock of available housing units grows. As potential customers increase, the AC adoption flow begins. The revised model includes both adoption through word of mouth and adoption through advertising. Once AC is installed, it is assumed that it will be replaced 100% of the time after a realized AC useful life. Potential and current stocks of AC installations are reduced by the number of units discarded as the home that they are in are demolished. AC installation stocks are initialized to zero.
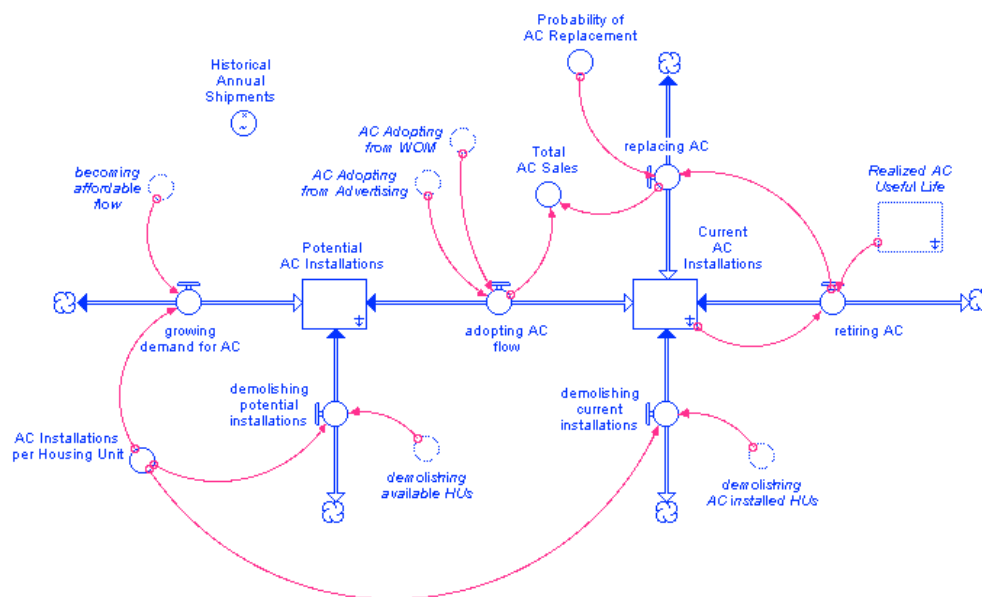

Figure 8: Updated Model - AC Installations Aging Chain

Air conditioning adoption sales are divided into two flows: AC adopting from word of mouth and AC adopting from advertising. The calculation components are shown in figure 9 below.

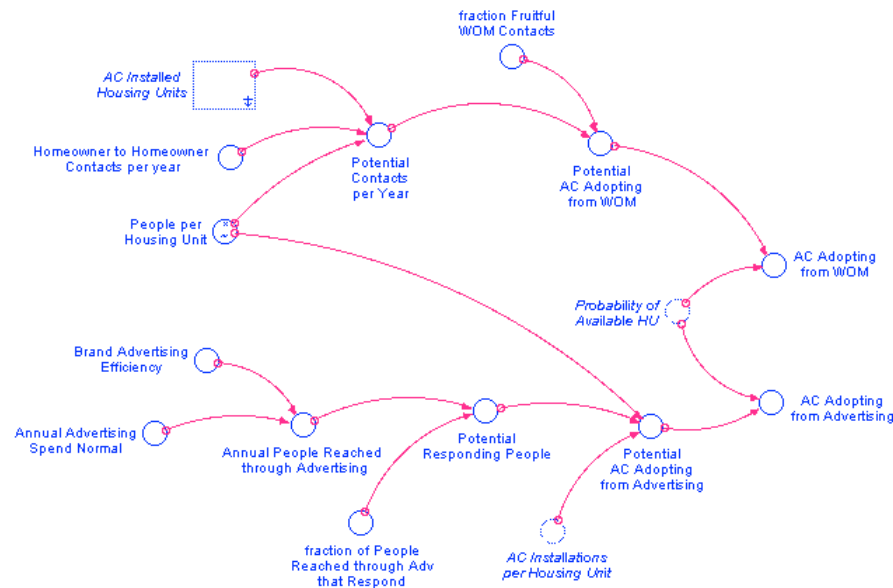[7] US Census data (http://www.census.gov/prod/cen1990/cph2/cph-2-1-1.pdf)

Figure 9: Updated Model - Calculation of Adoption Sales Flows

Because both word of mouth and advertising sales require people, these adoption flows include a calculation of the number of people per housing unit based on estimated historical values for US population and US housing units[8]. Adoption AC sales are limited by market saturation, the probability that advertising or word of mouth involves someone in an available housing unit (AC is affordable but not yet installed). Although the annual advertising spend is held constant through the model simulation, the flow of AC adopting from advertising serves only to seed the stock of AC installations and rapidly becomes an insignificant percentage of overall AC adoption sales.

The behaviors of the housing stocks are shown in figure 10 below. Total housing units (black) grow throughout the period, following historical trends. Unavailable housing units (red) decline as AC becomes relatively more affordable as a percentage of household income, but a "non-adopter" core is maintained throughout the simulation period. Available housing units (green) that can afford AC, peak in 1989 while the stock of housing units with AC installed (blue) grows rapidly (during adoption) from about 1990 to 2005 and then continues to grow with the total housing stock.
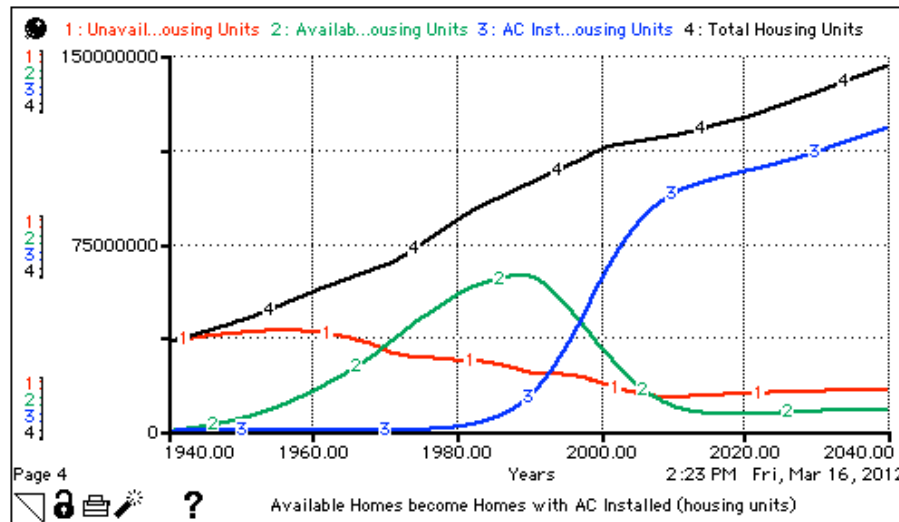

Figure 10: Updated Model - Housing Unit Stocks

The behaviors of the AC installation stocks are shown in figure 11 below. The number of potential AC installations (green) is proportional to the number of available housing units (figure 10). Similarly, the number of current AC installations (blue) is proportional to the number of housing units with AC installed (figure 10). while the added model structure produces an AC installed base behavior similar to the initial model, the AC installed base in the updated model grows somewhat faster and ends its growth somewhat sooner. This is a result of the added dynamics of AC affordability and is an important component to fitting the model behavior to known historical sales flow data (shown in figure 12).
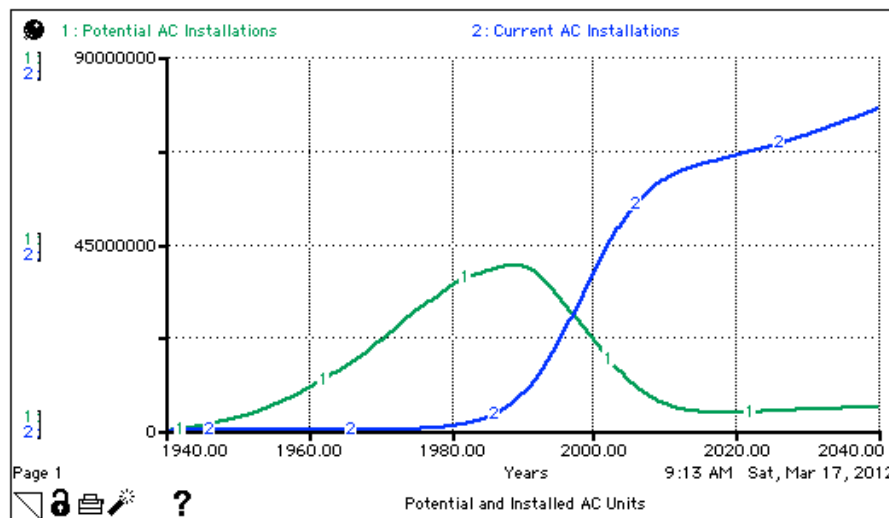

Figure 11: Updated Model - AC Installation Stocks

The resulting AC installation sales flows are shown in figure 12 below. Historical total AC units sales (black) are available from 1991 to 2011 (the extension of historical sales before 1991 and after 2011 should be ignored). Total AC sales flows from the model (red) track historical sales with the exception of short-term oscillatory behavior. The

model behavior as shown below misses the peak historical sales of 2004 and 2005, as well as the bottoming out of historical sales in 2009 and 2010, but does an excellent job of explaining the overall AC sales trend.
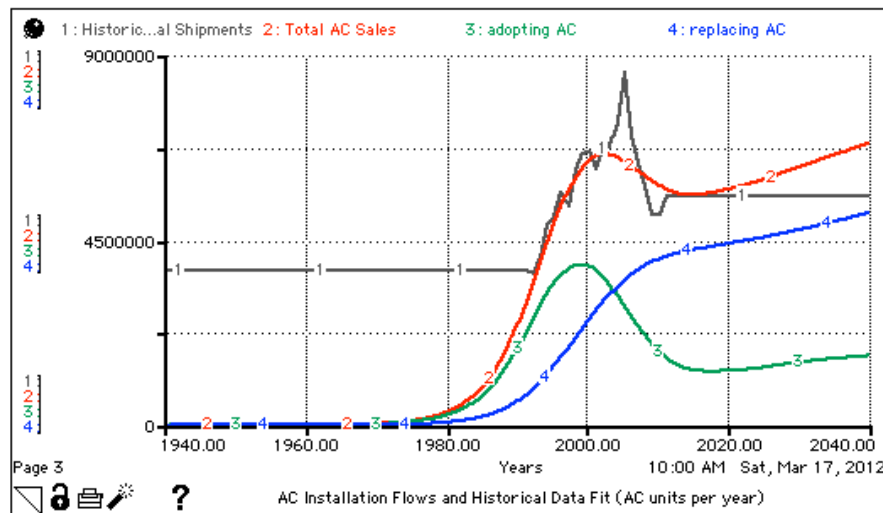

Figure 12: Updated Model - AC Installation Flows

The component flows of total AC sales, adoption sales (green) and replacement sales (blue) are also shown in figure 12. As in the initial model, adoption sales are a large portion of total sales (because of a 15 year average realized product durability) causing total annual AC sales to contract before reaching the sustainable replacement sales rate. Adoption sales remain above 1.3MM units even after declining because the US housing stock is forecasted to increase at a healthy rate and because some AC units are discarded prematurely at the end of a home's useful life. Even with a forecast of healthy gains in the US housing stock, after 2010, US AC sales grow at less than half the pre-2000 growth rate, and total US AC sales do not return to the prior sustained peak level of about 6.5MM units (1999 through 2004) until 2033.

AC useful life (which is being held constant throughout the model simulation) is a critical parameter to the behavior of both models. Several arguments support a "realized" AC useful life that is changing. The first argument is that the realized useful life of an AC unit has fundamentally changed since the product was first introduced. In this argument it is generally believed that AC unit assemblies have become less durable due to the introduction of more component parts, especially small mechanical devices such as sensors and relays that are prone to failure. This argument is largely anecdotal and lacks any solid historical data collection efforts. Differentiating between replaceable component parts (such as an expansion valve) that are part of AC maintenance, and core component parts (such as a compressor) that economically require AC unit replacement, makes the effect of this argument on useful life more difficult to measure. For this reason, a consistent, long-term change in AC useful life is not contained in the updated model.

The second argument that AC useful life varies concerns shorter-term issues. This argument says that realized AC useful life is a function of both manufactured product durability and consumer purchasing effects. Consumer purchasing effects include the acceleration or delay of an expensive durable goods purchase based on factors such as expected future price, current government ncentives (e.g. tax rebates), and current economic factors (e.g. availability of financing or consumer confidence). To recognize these shorter term influences on AC useful life, the model structure in figure 13 below was added.
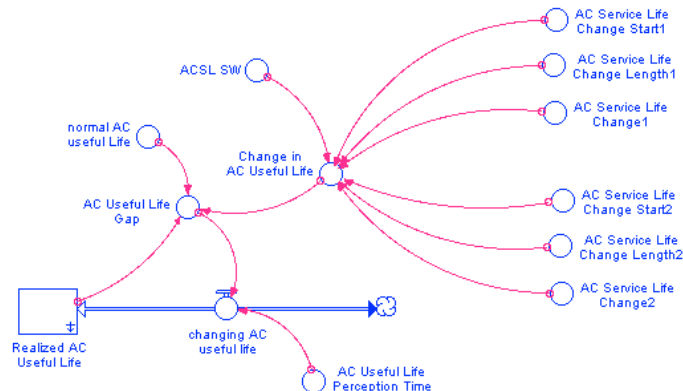

Figure 13: Updated Model - Calculation of Realized AC Useful Life

The realized AC useful life is a smooth of the long-term normal AC useful life and two modeled "shocks" resulting from factors believed to affect AC useful life. The first generally accepted shock to AC useful life is the result of governmental policy. The US Department of Energy increased the minimum efficiency of newly manufactured AC units by 30% beginning in 2006. This large increase in AC efficiency was generally expected to come with a similar increase in purchase price causing some consumers of AC units to accelerate purchases. In addition, an anticipated US Environmental Protection Agency policy (resulting from the Montreal Protocol agreement on global climate change) requiring widely used R22 refrigerant gas to be phased out, also increased the expected purchase price of a future AC unit. Consumer buy-ahead behavior was especially strong with property management (and government) installations where obsolescence for large numbers of AC units is planned. Adding to planned buy-ahead behavior, aggressive retail sales programs in 2004 and 2005 accelerated one-at-a-time AC unit sales. This AC useful life change (AC Useful Life Change1) begins during 2003, lasts for two years, and decreases the realized AC useful life.

On the heals of consumer buy-ahead behavior, it is generally believed that the overall (global) economic downturn of 2007 through 2009 had a measurable effect on the sales of US AC installations. Consumers of AC units are believed to have put off the replacement of AC units, opting to repair units that would otherwise have been replaced. This argument is supported by increases in the sales of "core" replacement parts (such as compressors) and the sale of substitutes to central AC (such as window AC) during this period of time. It is further argued that the prior recent buy-ahead behavior

effectively lowered the average age of installed AC allowing AC consumers to delay marginal replacements more easily. This AC useful life change (AC Useful Life Change2) begins during 2007, lasts for two years, and increases the realized AC useful life. The resulting fit between model and historical total US AC sales are shown in figure 14 below. Results are shown over a shortened time period (1980 through 2020) to better highlight the differences between data sets. Model results are in red. Historical data is in black (historical values plotted in the graph before 1991 and after 2011 should be ignored).
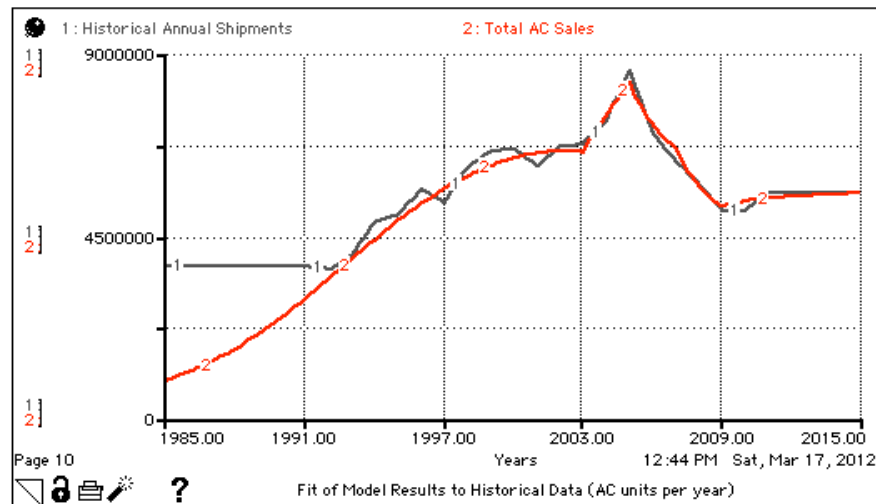

Figure 14: Updated Model - Model Results Fitted to Historical US AC Industry Sales

As can be seen in figure 14, using relatively few exogenous parameters, the updated model of US AC sales behavior produces an excellent fit to the available historical data. Careful estimation of one model parameter in particular, AC useful life, creates the necessary industry contraction and, with smoothed changes, causes the model behavior to match historical data closely.

One possible use of this model is to estimate the size of the future US AC industry in an effort to perform various business planning functions such as capacity planning. The value of AC useful life is critical to the model behavior and its value is difficult to estimate for the current US AC installed base. To gain a better understanding of likely future US AC industry sales, a sensitivity analysis on AC useful life was completed. The results are shown in figure 15 below. The chart in figure 15 shows total US AC sales for values of AC useful life of 13 (blue), 14 (red), 15 (pink), 16 (green), and 17 (gold) years. Fifteen years of AC useful life was used in the updated model results shown above (and produced the best fit of model results to historical data). Model sensitivity to AC useful life was tested by adding and subtracting two years (+/-13%) from the 15 year baseline value.
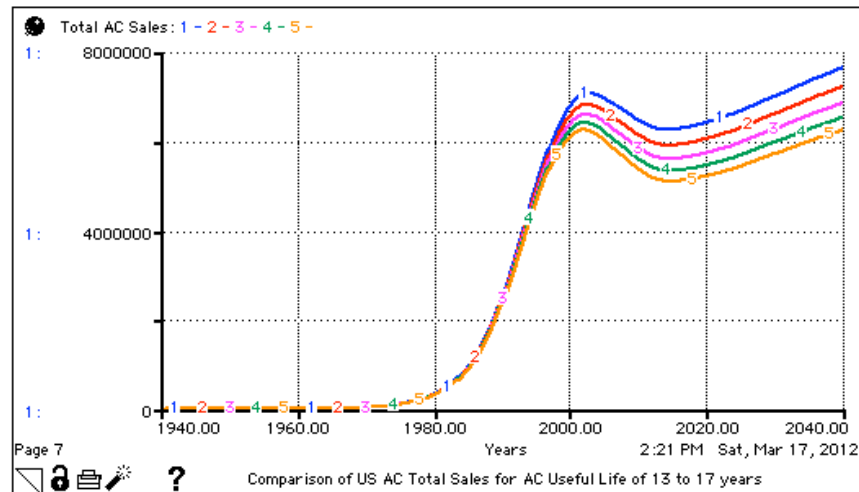
Figure 15: Updated Model - Model Sensitivity to AC Useful Life

Changes in total US AC sales as a result of changes to AC useful life are most significant after the year 2000, when adoption sales are contracting. Total US AC sales in 2015 using an AC useful life of 15 years are 5.64MM units per year. Total US AC sales in 2015 range from 6.30MM units per year (12% above the baseline) using an AC useful life of 13 years (blue) to 5.14MM units per year (9% below the baseline) using an AC useful life of 17 years (gold). In all cases the US AC industry sales contraction is significant at over 10% from the model's smoothed peak value and over 30% form the historical peak value. A 13% variation in AC useful life produces a plus or minus 10% variation in US AC annual sales. While this represents a fairly large range of possible future industry sales rates, it implies that we can eliminate certain overly optimistic and pessimistic forecasts. This will be discussed further in the next two sections.

Revised Reference Mode

Throughout the period described in this paper, the RSC management team interviewed suppliers and customers about the future condition of the US AC industry and continued their ongoing system dynamics modeling efforts in an effort to create better policy decisions. By 2010, a clear US AC industry sales trend had developed. A revised reference mode (including actual US AC industry unit sales through 2010) along with updated forecast scenarios is presented in figure 16 below.
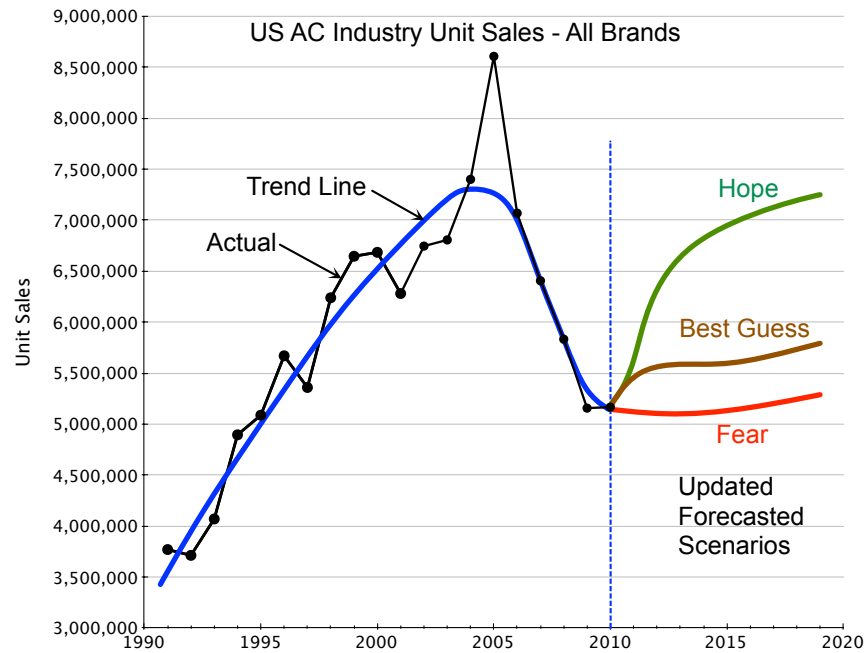
Figure 16: 2010 US AC Industry Reference Mode[9]

Industry results and continued modeling efforts had convinced the RSC management team that the industry sales contraction from 2006 through 2009 was a required one-time event due to the long useful life of AC units. The expected magnitude and pace of the required contraction, however, remained uncertain. Although actual data was available that indicated the timing and size of the industry contraction, RSC management was concerned about the affect of much discussed exogenous events (US Department of Energy 13 SEER efficiency mandate, the housing crisis, and general economic malaise).

Historical sales data show that the AC industry is prone to oscillations (a behavior not represented in the RSC models described in this paper). Does the recent sales contraction represent an overshoot of the sustainable replacement rate? Are sales likely to bounce back and by how much? Taking these concerns and modeling results into account, RSC management decided that a "best guess" forecast scenario (brown) was a modest improvement in total US AC sales (back to about 5.5MM units per year) followed by slow future growth as determined by the net increase in US population. This best guess scenario simplified RSC business policy changes. Since no drastic changes to industry sales were anticipated, RSC management could turn their attention away from capacity planning policies and focus on competitive dynamic policies.

The magnitude of the contraction was known to be a function of AC unit useful life, but estimating the average realized useful life for AC units installed across the US is a difficult task. RSC management was using a range from 12 years (a value thought to be weighted to southern and coastal installations where useful life is relatively short) to 20

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[9] Air Conditioning, Heating, and Refrigeration Institute, 2011, "Central Air Conditioners and Air-Source Heat Pumps Historical Data".

years (a value thought to be weighted to northern installations where operating hours are relatively few and useful life is relatively long). Because the territory served by RSC is considered northern, decisions were based on the longer end of AC life. This bias developed into the "fear" forecast scenario (red) where US AC industry sales stagnate at minimum 2010 levels with slow future grow again dependent on the net increase in US population.

Throughout the period described in this paper, RSC's suppliers continued to forecast significant future growth. The argument to support growth centers around a belief that while record US AC industry sales in 2005 may not be achievable anytime soon, the sustained industry sales rates of approximately 7MM units during the period from 2000 to 2004 are achievable once external economic factors become favorable. With modest growth in the AC installed base (especially when residential new construction recovers), peak sales of 2005 of 8MM+ units will be achieved shortly thereafter. This argument relies on the assumption that AC adoption sales had ended by the year 2000, making 7MM units the sustainable US AC replacement rate. Using data provided to RSC by its suppliers, the "hope" forecast scenario (green) was created.

RSC management is significantly concerned about the prevalence of the hope scenario among its suppliers. Believing that the US AC industry will return to rapid growth over estimates the size of the installed base and implies that the 20% to 30% unused capacity being held by manufacturers will be required in the near future. RSC management sees the unused capacity as excess overhead expense while the US AC market enters perhaps the most competitive phase of its lifecycle. Increased competition between brands sold through a multi-step sales channel will make any excess expense a significant competitive disadvantage.

Reconciling Conflicting Forecast Scenarios

The more system dynamics modeling that the RSC management did, the more their preferred forecast scenario diverged from the forecasts being provided by industry suppliers. The 2010 RSC forecast scenario update (figure 16) included a significantly optimistic "hope" scenario because of forecasts from AC industry suppliers such as the two shown in Figure 17 below. (The vertical scale is in US AC industry units and is left blank on purpose.)
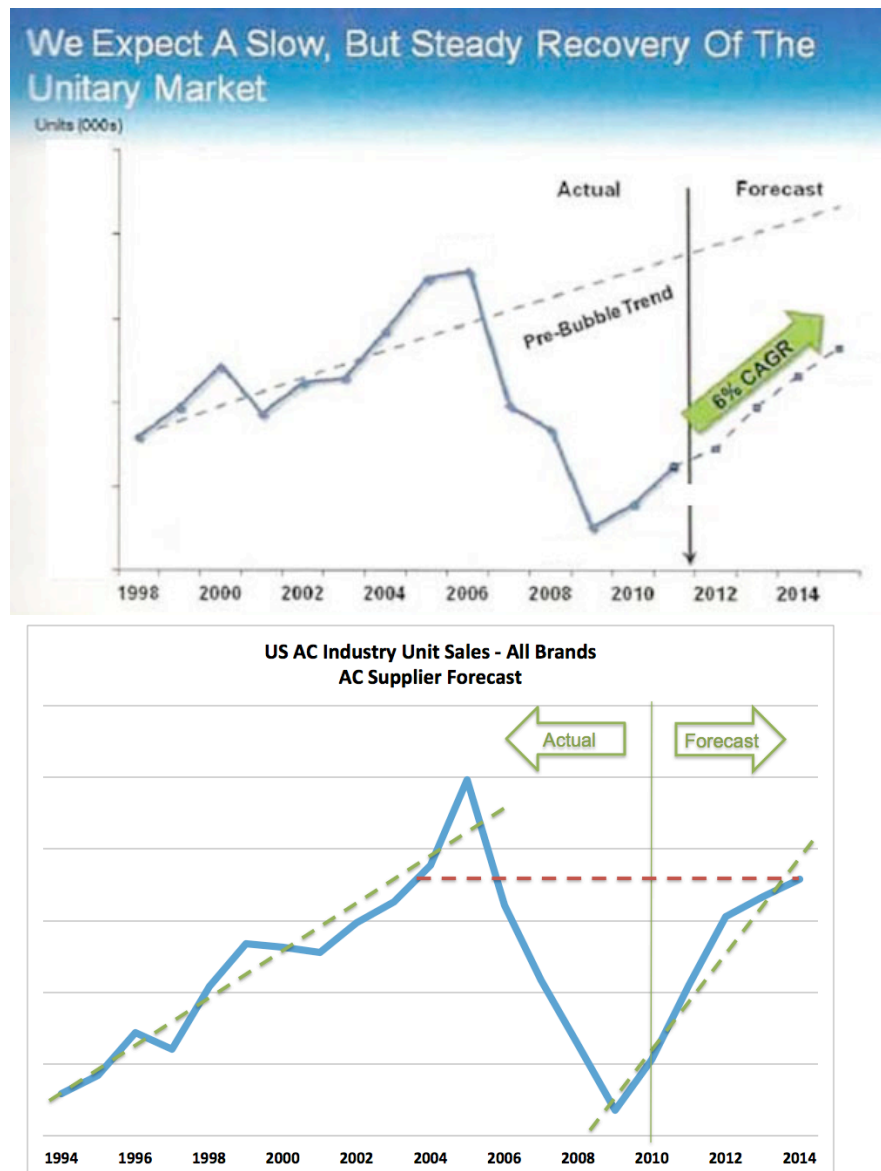
**Figure 17: RSC Supplier-A (top) and Supplier-B (bottom)
US AC Industry Unit Forecast for 2012 through 2015
(vertical scale omitted on purpose)**

These two charts came from different companies. While each of these two industry suppliers has a somewhat different view of US AC units, the two charts are remarkably similar in the following ways:

• The industry upturn begins in 2010 and represents a growth rate that significantly exceeds the industry growth rate from 1994 through 2004;

• The 2009 US AC industry unit sales rate is roughly equivalent to 1994 US AC industry sales rates; and

- The projected 2014 US AC industry unit sales rate is projected to be equivalent to 2004/2006 (omitting the peak in 2005) sales rates.

Both supplier forecasts imply that industry sales will grow in five years (from 2009 to 2014) by the same amount that the industry previously took ten years to grow (from 1994 to 2004). Using the causal arguments of system dynamics modeling, RSC management believes that the growth in prior (1994 to 2004) industry sales had the advantage of peak adoption sales rates, whereas the upcoming (2009 to 2014) growth in industry sales will be dependent on replacement sales and population driven increases to the installed base. During 2009 to 2014 adoption sales will be declining. Although the suppliers' forecast models claim to include market saturation (and thus the ending of adoption sales), their total industry sales forecast is very different.

Reconciling these perspectives requires examining the underlying assumptions of each forecast. In the RSC causal argument, adoption sales are treated endogenously over the lifetime of industry sales growth and market saturation. If WOM adoption feedback is removed from the model (made exogenous to the model), then the magnitude and timing of adoption sales must be estimated outside of the model. In addition, including the entire industry lifecycle (RSC causal model) has the advantage of calculating the installed base of AC units by accumulating adoption and replacement sales from the beginning of the US AC industry. (The installed base of US AC units is an unknown quantity.) In contrast, the supplier model has a shorter time-frame and depends on a beginning installed base of AC units estimated outside of the model.

As stated earlier, RSC suppliers often argue that 2004/2006 industry sales were "almost entirely" replacement sales and thus represent a sustainable replacement rate based on the implied installed base of AC units. Underlying this argument is the mental model that the US AC industry will experience "S" shaped growth, saturating smoothly to a sustainable replacement rate. This assumption leads to an installed base calculation (AC units) equal to the 2004/2006 industry sales rate (AC units per year) times an estimated average useful product life (years). Calculating the installed base using assuming smooth "S" shaped growth (without an endogenous explanation for the size or timing of adoption sales) will over estimate the size of the installed base.

Despite several interviews with supplier business unit managers, the details of the suppliers' forecasting models have been unavailable. However, these models are often described as sophisticated, multi-page spreadsheets containing historically vetted calculations involving a large number of influential and significant factors. It is assumed from this description that factors known to effect AC sales such as weather, rates of residential new construction, availability of credit, consumer confidence, etcetera are correlated to historical sales trends and used to forecast industry sales trends. One difficulty with a correlation method is that the bell-shaped behavior mode of AC adoption sales is not causally dependent on any of these "influential factors". Thus any correlation between industry sales and "influential factors" that ignores underlying adoption sales growth will become increasingly incorrect as adoption sales level and then decline. The magnitude of the correlation method error will be significant when

adoption sales are a large portion of the overall industry sales (as they are with durable goods).

As the disparity between the RSC "best guess" and supplier "hope" forecast scenarios became difficult to reconcile, RSC management became increasingly vocal with industry suppliers in hopes of gaining insight into a more confident forecast. The causal arguments for US AC industry decline (captured in the RSC modeling efforts) were often presented to the executive management of industry suppliers. This was done using verbal arguments at annual supplier-wholesaler conferences, written arguments in the form of a brief executive memo, and comprehensive presentations when scheduling allowed. The purpose of these communications was to gain insight into a better RSC forecast model and to convince suppliers that product durability is a dual edged sword (durability is a part of product quality, but durability also dictates the magnitude of annual replacement sales).

The reception has been mixed. Some people can repeat back the fundamental endogenous adoption logic, but do so in a way that says: "I understand your argument, but it is not what we choose to believe." Others just remember the outcome of the endogenous adoption logic, such as the fortune 500 CFO who said: "I remember you! You are the guy with the crazy idea about a permanent US AC industry contraction!" But he could not remember the logic supporting this outcome. Perhaps the most discouraging reaction is summarized by an industry marketing executive who sat through a brief presentation of the endogenous adoption model and then said: "I do not care why the industry numbers are going to be the way they are. I am only concerned with increasing (my brand's) share of market." Amazingly, product durability, which is exclusively determined by the manufacturers of AC equipment, can be thoughtfully changed to alter share of industry sales. Refusing to understand the causal endogenous adoption model stands in the way of understanding a way out.

Conclusions

When RSC's fourth generation president assumed responsibility for the future health of the business, he was committed to preserving the wisdom of prior generations who built the business. Already a 77 year old company, he knew that there was much to be learned from the successes of the past. His predecessors' wisdom included the ability to recognize fundamental industry change and to facilitate new business policies to take advantage of the opportunity that significant change creates. The history of RSC provides clear examples of taking advantage of fundamental industry change. RSC was founded as an opportunistic refrigeration retailer when mechanical refrigeration was an expensive and newly available technology. When servicing and rebuilding commercial refrigeration systems became more profitable, RSC was transformed into a regional refrigeration service company. When accelerating industry growth required wholesale distribution, RSC again transformed its business to take advantage of the opportunities.

Understanding the opportunities of future AC industry changes was critical to making successful business policy decisions. Using system dynamics modeling as a part of

developing strategy gave RSC management added confidence about the likely future of the US AC industry. System dynamics modeling was used by RSC management as a tool to incorporate conflicting views of the future into a realistic causal description of industry opportunity. Unexpected model results created a sense of curiosity and learning that would not have occurred otherwise. The continuing dynamic nature of the US AC industry gives RSC management a good reason to keep using system dynamics modeling as a tool when considering changes to business policy.

RSC management's successful use of system dynamics modeling stretches beyond the US AC industry dynamics described in this paper. As competition grows into a battle for brand share of market, RSC management has extended their modeling efforts to understand the dynamics of brand rivalry, contractor loyalty, and marketing expenditure policies. RSC management has also used system dynamics modeling to create prudent business diversification and expansion policies.

In addition to core business policy, the US AC industry is subject to several important federal policies. Air Conditioning is one of the largest users of electricity in the US. This makes AC efficiency an important part of the energy sustainability dialog on a regional and national level. In addition, refrigeration technology is dependent on the use of a refrigerant gas. While formulated for efficient heat transfer in a closed mechanical system, leaked and vented refrigerant gases are known to damage the earth's ozone layer and contribute to global climate change. Because of the relatively long useful life of air conditioners, authoring successful energy efficiency and environmental policy requires a strong understanding of the stocks and flows in this system. RSC management believes that US EPA and DOE policy makers would benefit from a similar use of system dynamic modeling.

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Biography

Warren Farr received his Master of Science in System Dynamics from Worcester Polytechnic Institute in 2011. He has been working in the heating, ventilating, air conditioning, and refrigeration industry as a wholesaler since 1993. Prior to learning to operate a wholesale business, Warren worked in the computer industry developing and marketing network control products, and as a contractor to the military developing communication and targeting systems. He has a Bachelor of Science degree from Duke University and a Master of Business Administration also from Duke.