Process Improvement of the Emission Decal Design and Release Process Utilizing a System Dynamics Approach

by

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PART I – INTRODUCTION AND HYPOTHESIS

Chapter 1. Introduction and Definitions

1.1. Problem Statement and Objectives

In the past ten years, automobile manufacturers have spent a growing amount of money on recall campaigns and late fixes brought about by emission decal problems, due in part because engineers and management do not fully appreciate the dynamic complexity of the emission decal design and release process. In particular, because the decals are technically simple, people incorrectly assume that the informational and process complexity is also simple. As a result, practices and policies for managing the entire decal design, release, and installation processes inevitably lead to difficulties. Poor systems understanding has ultimately resulted in increased recall campaign costs.

Using many of the key tools taught as part of the Massachusetts Institute of Technology's System Design and Management (SDM) curriculum, I will endeavour to briefly describe the relevant details of the complicated emission certification and emission decal design processes and their inherent difficulties. An overview of the process is required to better see where the system often breaks down, and to better use the tools taught in the SDM curriculum to suggest where changes might be appropriate to reduce difficulties and warranty costs. Using these tools, I will build a case to support my hypothesis that the misunderstood complexity of the emission decal design and release process drives errors, and suggest remedies to help alleviate the problems.

Much of this thesis focuses on the certification and emission decal design and release efforts of Ford Motor Company (Ford) and General Motors (GM). Many of the leading edge emission efforts are focused in the United States, so although efforts for overseas markets are briefly described, the primary focus is of this paper is on the system used by Ford and GM to meet requirements in the North American market.

1.2. Research Methodology

Various research methodologies were used to gather data for this thesis. The author did not rely on just one method of research to obtain the information contained in this paper. Information gathering and research techniques included:

- Interviewing three current emission decal design engineers, three past emission decal design engineers, and the current emission decal design supervisor.
- Ongoing discussions with the emission decal design and release supervisor.
- Ongoing discussions with the 6-Sigma black belt focusing on in-plant assembly issues.
- Attendance at the Emissions Label Benchmarking meeting between DaimlerChrysler, Ford and GM.
- Visiting an auction yard in Flat Rock, Michigan to do an informal audit of recent model year emission decals of various manufacturers.
- Internet web search for emission regulatory statutes and previous recall campaign information.
- In-person and electronic mail (e-mail) correspondence with representatives of other automotive manufacturers beyond those present at the aforementioned Emissions Label Benchmarking meeting.
- E-mail correspondence with manufacturers' regulatory liaisons.
- Utilizing past experience as both a regulatory liaison and emission decal design and release engineer.
- Utilizing information learned in Six-Sigma green-belt training.
- And perhaps most importantly, utilizing information learned as part of MIT's SDM curriculum.

1.3. General Background Information

The Vehicle Emission Control Information (VECI) decal (shown in Figure 1) is a mandatory model-year-specific label required by the United States Environmental Protection Agency (EPA), California Air Resources Board (CARB), and various foreign governments including, but not exclusive to, Canada, Mexico, Philippines, Columbia, Venezuela, Taiwan, Korea, and Chile. The decal is required to be installed underhood and is subject to emission recall campaigns if incorrect. One decal is required by regulation per vehicle, with location in part determined by the type of certification (more on this point in Chapters 3 and 10). CARB requires that a vehicle be labeled when it leaves the assembly plant for transportation to a point of sale. However, it is also deemed illegal for a vehicle to have a decal installed and shipped from the plant prior to the vehicle's engine group being certified by the government agencies.

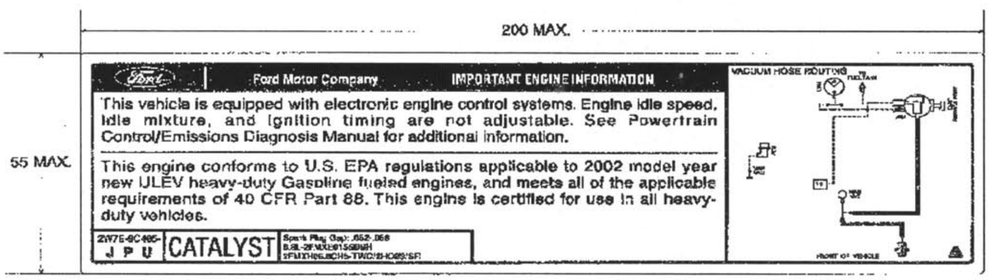


Figure 1: Example VECI Decal

1.4. Image / Timing

The internal image of the emission decals varies by company. However, generally the emission decals are seen as an 'easy' part to design and release due in large part to the relative technical simplicity of the part. Essentially it is a 2-dimensional part that utilizes known materials and adhesives. The end result, the decal, is not cutting edge in color, material, design, etc.

However, the informational complexity of the part rivals or surpasses many of the traditional engineering parts in existence. The compilation of information from the numerous sources and the complications of coordinating the vehicle being built to the correct decal make attention to detail paramount. Quoting Rechtin and Maier[1], "one person's system is another's component". Or, in the language of emission decals, what some people (assembly plants, upper management, etc.) view as a just another part that needs to be delivered in a certain timeframe and in a certain quantity to fit into their processes, others must view as a complicated system that requires attention to detail, 'tree' diagrams to ensure full vehicle line coverage, and numerous customers who help to define the often conflicting user requirements. Rechtin and Maier warn us, "don't confuse the functioning of the parts for the functioning of the system". This can appropriately be applied to emission decals as well.

Because the emission decal design and release activities must effectively interweave with numerous other largely independent processes (the program teams often work largely independently of one another through launch), each program tends to demand preferential timing. There are only a limited number of decal design and release engineers supporting all programs (one engineer for GM and three for Ford covering all North American vehicle lines)[2], and the decals are often viewed as a commodity by program teams and assembly plants instead of as systems as the experienced design and release engineers view them. This leads to tremendous conflict and raised stress levels for all involved.

1.5. Six-Sigma Efforts

Ford is taking the forefront on employing six-sigma efforts to reduce warranty costs as a direct or indirect result of emission decal design, release, or installation errors. Current six-sigma efforts are focusing on the differences in methods used by the Big 3 (DaimlerChrysler, GM, and Ford) and how lessons learned by others could be shared. A joint benchmarking process has been started, with periodic meetings where the responsible parties come together to discuss issues of mutual importance. However, the boundary currently defined by Ford's six-sigma efforts is looking at how the decals are printed and installed in the plant. This is an area worthy of investigation, but the boundary of their system is defined differently than that of this thesis. This thesis is attempting to use System Dynamics and other tools taught as part of the

System Design and Management curriculum at the Massachusetts Institute of Technology (MIT) to look at individual case studies and to develop models to help understand the underlying issues.

Chapter 2. Generation of Hypothesis

Based upon the author's experience, research, and discussions with personnel currently involved in the emission decal design and release process, a realization occurred that the various affected parties were often not communicating as clearly as was necessary to facilitate a virtually error-proof process. Key players in the process did often not understand how the entire certification, design, release, and installation process fit together. In fact, numerous meetings were attended where these key players could barely communicate their needs. This chapter looks at the need for a robust process, and develops a basic hypothesis as to the underlying causes currently preventing such a process. These ideas will be further investigated in later chapters.

2.1. Recurring Themes

2.1.1. Fines – Possible and Actual

Different manufacturers reported very different experiences with fines. Fines are generally not the norm. However, one example of a fine being levied was in October of 2001. CARB fined Ford $150,000 for 3000 vehicles being incorrectly labeled[3]. The $50 per vehicle fine is but a fraction of the possible fine that could be imposed for a pattern of infractions and a failure to comply with Health and Safety Codes. In fact, the maximum fine *per vehicle* is $27,500. Instead of the $150,000 fine, Ford could have been liable for an $82.5M fine. It is unlikely that such a penalty would be imposed or that an OEM would not contest it in court if the regulatory agencies tried. However, recent court rulings such as on the TFI (thin film ignition) modules in California[4] where a judge ordered the recall of 1.8 million vehicles – the first of it's kind not initialized by the National Highway Transportation Safety Association (NHTSA), leaves the

Original Equipment Manufacturers (OEM's) reluctant to seek relief in the California or Federal court systems.

2.1.2. Labels Late / High Stress

Another recurring theme is the stress incumbent upon the handful of engineers responsible for designing and releasing all the decals that get placed on all North American built products. These engineers are involved across vehicle lines and the decals are often the last part delivered to the assembly plant. Multiple vehicles lines try to pull the resources according to their needs, rather than the needs of the company as a whole. With multiple vehicles launching at very close dates, resources can be spread very thin. Individual product lines require meeting coverage, e-mail notes, telephone calls, delivery plans, etc., that take time away from issue resolution and actual job completion and affect job productivity.

If an error occurs, whether it was that of the design engineer or not, they are usually called upon to answer the question of what went wrong and to fill out incident reports designed to prevent the same issue from reoccurring. The level of visibility given to these positions tends to be greater than that afforded to other vehicle engineering positions. However, much of the visibility is negative due to confusion that mistakenly arises from equating technical simplicity with process simplicity. Today, processes have been implemented that in the case of a recall campaign, a Director (at least 3 levels above the design engineer) or higher must go before an internal review committee to ascertain how the problem arose. In actuality, the Director tends to bear the brunt of the internal anger surrounding any recall. Whether the Director accepts this venting for what it truly is or passes it along to those working for him or her depend upon the individual. If the anger is passed along or if an individual is sought out on whom to assign blame, this can take an adverse effect on morale and may precipitate the move of well-meaning experienced engineers into other positions.

2.1.3. Six-Sigma Themes as Applied to Emission Decals

The six-sigma process examines themes that tend to reoccur in processes that habitually breakdown. For six-sigma, these are:

- Past success has bred arrogance
- Reliance on trial and error
- Little focus on quality measurements
- Functional silos inhibit collaboration
- Rewarding of fire-fighting behaviour
- Dependence on inspection and rework

Each of these ideas from six-sigma can be evaluated to see if it applies in the case of emission decals:

- *Past success has bred arrogance.* Perhaps a better phrase for emission decals may be "Past success has bred apathy." Because greater than 99% of all vehicles do not have any issue with their emission decals, there has been a reluctance to develop better methods of reducing the errors in that final 1%. There are other more pressing issues that tend to take away attention and resources from any improvement efforts. Likewise, this is not a glamorous issue on which the reputation of fast climbers is solidified. Instead, as most process issues become, it is an extremely troubling issue that cuts across organizations that has no simple answers.

- *Reliance upon trail and error.* Trial and error is a reality in the emission decal design and release process. As errors are discovered, studies are made on how to prevent that error from happening again. Little effort is made to proactively improve the entire process before errors are made. The engineers and their supervision do make improvements at the low level at which they can implement, but large fundamental changes are nearly impossible to implement at higher levels.

- *Little focus on quality measurements.* Lack of attention on quality measurements also appears to be true for the emission decal process. No time or resources are allotted to measuring the quality improvements. Many small changes have been implemented that have resulted in errors being caught before going into the field, but few metrics exist to clearly demonstrate these improvements to an outsider or a process sceptic. The modelling in Chapter 7 attempts to quantitatively demonstrate the effects of improvements or degradations in the process.

- *Functional silos inhibit collaboration.* This is a very large issue whether it is between Ford's Vehicle Environmental Engineering (VEE) and Core and Advanced Powertrain (CAPE) (more on this subject in Chapter 6) on what to include on the decals, between the emission decals design engineers and the assembly plants on release timing, between the emission decal design engineers and the individual vehicle lines on priorities, between the design engineers and the calibration teams on the accuracy of information provided, etc. Different groups have different priorities and this can significantly affect the entire process as a whole.

- *Rewarding of fire-fighting behaviour.* The system tends to reward the person or teams who solve an existing problem rather than the person or team who prevents an error from occurring in the first place.

- *Dependence upon inspection and rework.* The emission decal design process is moving in this direction, but up to now, there has been very little in the way on inspection and rework until it is too late and the decals are out in the field. It is the ultimate goal that inspection should not be necessary if the process is robust, but until such time as the process is demonstrated to be robust and to meet intent on a more consistent basis, some degree of inspection will be required. In The Machine That Changed the World, Womack et al reiterate the shortcomings of inspection by telling us "quality inspection, no matter how diligent, simply cannot detect all the defects"[5]. On the other hand, common sense dictates that even though prevention is preferred, detection is often our reality. However, inspection and rework should not take the place of designing a robust process.

2.1.4. Additional Themes Discovered

In addition to elaborating on these six-sigma themes, several other specific themes were discovered in the course of doing research to support this thesis. These six additional themes play an important role in the development of the hypothesis and several serve as key points to investigate with System Dynamics modelling in Part III.

- *Understating the detrimental importance and impact of late changes.* It cannot be stated strongly enough: late changes cause major disruption and force engineers to redo earlier work, often several times. Several side effects can occur ranging from employees not putting their full efforts into early drafts expecting late changes, to others not giving the emission decal engineers the information they need in a timely manner because of the impending rework. Discipline appears to be missing, especially at the highest levels of the company that dictate strategy. In an example further defined later, changes in projected compliance in the 2007MY precipitated late changes for the 2004MY that was less than a month away from launch. Clearly "we have met the enemy and he is us".

- *Little trust and no enforcement of the procedures in place.* Many procedures such as sign-offs and validation checks have been implemented that were designed to help ensure correct emission decals in the field. All too often these procedures are seen as an inconvenience or a mere formality to those tasked with complying. If a subsequent error still occurs, it is not the checkers that gave their 'OK' that are taken to task, rather it is engineers who rely upon these other people for correct inputs who are often blamed and chastised. This is introduced into our model later as less than perfect checking quality.

- *Understating the importance of experience.* The experience of the engineers doing the design and release work is often not recognized as important to the process. Rather, in part due to the low technical complexity, those engineers are often seen as interchangeable parts. When activities occur correctly, little attention is paid to the design team.

- *Understating the detrimental effect of constant stress on job performance.* Constant late changes, angry phone calls, incident reports, threats of recall, explanations to senior management, etc. take their toll on the engineers. Each individual is different, but after interviewing six emission decal engineers both past and present, there appears to be a 'tipping point' at which the typical emission decal engineer starts to seek other job responsibilities.

- *Mistakenly equating technical complexity and process complexity.* The emission decals are a 'simple' part technically. However, the complex regulatory environment, the level of detailed information required, the numerous information hand-offs, and constant churn of process-inexperienced key players results in a very complex component (or system, depending upon the perspective). Often upper management, with the inherent belief that it is impossible to make a mistake on such a simple part technically, questions any decal recall campaign. This impacts the raise and promotional opportunities of the engineers, negatively impacts morale, and often speeds up the search for a new job. Furthermore, this immediate questioning by upper management does not often lead to valuable process improvements; rather the root cause and subsequent preventive action are usually a band-aid on a much larger problem.

- *Mistakenly believing that all time slippage can be recovered in the final step.* Since the emission decal design and release is the end product of the certification process, it does not usually meet the internal timetable for the release of all parts to the assembly plant. With late changes upstream and subsequent delays in the certification process that will be highlighted by a critical chain example, the decal design and release process' timing is often condensed to meet the relatively inflexible Job #1 date. This is impractical and places stress on the system. As Goldratt says in The Goal[6], everything should be subordinated to the bottleneck. In effect, everything should be cleared out of the emission engineers' way so that they can do their jobs quickly and effectively when they have the necessary information. Instead, time slippage usually results in more meetings, calls, explanations, containment plans and the like which only leads to more unnecessary slippage.

Taken as a whole, this summary of recurring themes serves as a hypothesis for what specifically can be improved in the emission decal design and release process:

- Train everyone - engineers, managers, and executives alike - on systems engineering principles and how their work and decision timing impacts the overall process.
- Eliminate or significantly reduce late changes.
- Foster and reward *process* technical maturity. Turnover of personnel in isolated programs leads key process players to be unaware that their changes often drive decal changes.
- Develop cross-functional and cross-divisional teams to develop system improvements.
- Electronically tie together the complete process and hold those responsible for data input responsible for both timing and accuracy at each step.
- Reduce stress on individuals by removing barriers to their work.
- Do not settle for 99%+ accuracy. Spend the money to drive out all error modes. The cost to do so may be greater than the annual recall costs, but cost of recalls goes beyond the immediate financial cost to the company.

Many of these suggested improvement ideas will be specifically addressed later in the System Dynamics models.

PART II – REGULATIONS AND COMPLEXITY

Part II of this thesis delves into the regulations, complexity, and ambiguity in the design and release of emission decals. A thorough understanding of potential error modes is necessary as a precursor to the development of the System Dynamics models in Part III. The numerous choices and contradictions in the regulations and legal interpretations also factor significantly in the complexity facing those intimately involved in the design and release process. It is a supposition of this thesis that complexity is not routinely ignored, but rather not fully recognized and appreciated by those who can affect the most significant changes to the process. It is the goal of this thesis to increase awareness of the emission decal design and release process and suggest policy changes that can assist the OEM's.

Chapter 3. Regulatory Background

Regulation complexity in the United States is not isolated to just emission decals. However, emission decal regulation complexity drives significant difficulties for design engineers, release writers, and installers alike. Two different regulatory agencies in the United States, the U.S. Environmental Protection Agency and the California Air Resources Board promulgate often conflicting regulations regarding emission decals. An understanding of the basic underlying regulations is absolutely essential to increase awareness of the inherent complications in the process and as a starter for the System Dynamics models to follow.

3.1. Recent History of Recall Campaigns

The emission decals are treated as recallable emission control devices. If incorrect information is printed on a decal, or if the wrong decal gets placed on a vehicle, it is subject to recall. Unfortunately, the process complexity for major OEM's has resulted in many such instances of recalls in recent years as the complexity of information required has increased substantially. For instance, in October of 2001, CARB fined Ford $150,000 for 3000 vehicles being incorrectly labeled[7]. Ford process improvement efforts have focused on in-plant procedures for correctly installing the decal indicated on the build sheet on the correct vehicle. Although this may sound like a simple task, the Econoline example to be shown later in Chapter 4 illustrates a case where 30+ decals, all the same size, with information irrelevant to the installer, have different three character suffixes which are used for installation. If the vehicles come out of order, it would be possible for numerous vehicles all to get the wrong decal installed. Although in-plant installation is the focus of six-sigma efforts, it is just one factor in the System Dynamics models of Chapter 7-10.

Looking at the emission decal recall campaigns of one OEM, during a recent 5-year period, approximately 160,000 thousand vehicles were campaigned due to incorrect or missing emission decals, with a corresponding direct cost of nearly $800,000. Several of the particular cases will be modeled in the Chapters 8-10.

Although the dollar value of the emission decal recall campaigns is relatively low compared to many other recall campaigns, the negative publicity generated by these campaigns tends to increase upper management attention on the issue. It has been stated internally that the negative attention from emission decal campaigns leads the public to believe that if a 'simple' part such as a decal can result in an error, then manufacturers may make more errors on technically difficult parts. Therefore, the cost of these recalls is greater than the stated monetary costs.

3.2. EPA – 40 CFR Part 86

The United States' federal government has given the EPA authority to promulgate emission standards and regulations. Title 40 of the Code of Federal Regulations (CFR) is titled 'Protection of the Environment'. Part 86 is titled 'Control of Emissions from New and In-Use Highway Vehicles and Engines'. This part is the one that most directly affects the emission certification of today's motor vehicles[8]. However, labeling efforts often require the engineers to cross-reference multiple regulatory passages to determine applicability. For instance, §86.095-35[9] is the often-used general information section on emission labeling, §86.1735-01[10] is the labeling information for the National LEV program, and §86.1807-01[11] is another general applicability section. The differences between sections are often subtle, but many of the important nuances of the emission decals are *seemingly* small. For instance, the National LEV program indicated that all vehicles should be certified according to California regulations. Section 86.095-35 states that the certification and in-use standards should be included on the decal per Federal regulations, but Section 86.1807-01 provides an important proviso, "In lieu of this requirement [to include exhaust emission standards], manufacturers may use the standardized test group name designated by EPA."[12] This is an important, yet subtle, difference that will be revisited later due to the extra revisions necessary for a coordinated change (Chapter 8) if an OEM does not follow this provision.

3.2.1. Vehicle Certified

There are two general types of possible Federal vehicle certification. The first is full vehicle certification. This means that the engine / body combination traditionally thought of as a vehicle is certified on a chassis dynamometer where an operator drives the vehicle following a prescribed drive trace on a single 48" dynamometer in a test laboratory setting. Depending upon whether it is classified as a car or truck, and also the weight class, the vehicle must meet emission standards over the full useful life of the product (100,000 miles for cars and light-duty trucks <5750# Gross Vehicle Weight Rating (GVWR); 120,000 miles for trucks >5750# GVWR). Numerical standards exist for Non-Methane Organic Gases (NMOG), Carbon Monoxide (CO), and Oxides of Nitrogen (NOx). There are numerous emission standards to which a vehicle can be certified (Tier 1, TLEV, LEV, ULEV, etc.). The corresponding numerical standards are described further in Appendix A, but it should be noted that in Appendix A these terms (Tier 1, TLEV, etc.) correspond to different numerical values depending upon vehicle classification and weight class.

Traditionally, all passenger cars and trucks under 8500# GVWR are certified by the method described above. The emission decal for a vehicle certified by this method is required to be a "permanent, legible label…affixed in a readily visible position in the engine compartment"[13]. This provision is important and will be revisited later in the Continental case study of Chapter 9 where decal location played a central part in the resulting recall campaign.

3.2.2. Engine Certified

Contrary to the vehicle certification described above, heavier vehicles are usually engine certified (vehicles up to 10000# GVWR can be certified by the vehicle method, but must meet emission standards of the heaviest <8500# GVWR (LDT4) weight class). Instead of a full vehicle being 'driven' on a chassis dynamometer, an engine is certified on an engine test stand. As stated above for full vehicle certification, there are numerous emission standards to which these heavy truck engines (HDE's) can be certified.

But instead of a vehicle being certified, in this case it is the engine that is certified. Correspondingly, the U.S. EPA requires that the emission decal stating compliance with the HDE standards "shall be affixed to the engine in a position in which it will be readily visible after installation in the vehicle and shall be attached to an engine part necessary for normal engine operation and not normally requiring replacement during engine life"[14]. In some instances these decals are installed at the engine plant and in other instances they installed at the vehicle assembly plant. The design and release engineer has ultimate responsibility as to where the decal application takes place. Also, one of the domestic OEM's (Ford) chooses to install a courtesy copy of the engine decal on the vehicle chassis for readability purposes. This regulatory discrepancy plays a key role in the engine label recall campaign described further in Chapter 10.

However, decal placement is just one difference between the decals for these different types of certification. Header information and compliance language are two other big differences that must be created correctly. These will be addressed in the next chapter on informational complexity.

3.2.3. Evaporative Emissions

Underhood evaporative emissions decals are also required for Federal certified vehicles greater than 8500# GVWR. These decals are independent of the aforementioned (exhaust) emission decals, but are typically designed and released by the same engineer that releases the greater than 8500# GVWR (exhaust) emission decals. Although the number and complexity of these evaporative emission decals is significantly less than the other decals, many of the same issues exist in regard to placement, release, and transfer of knowledge to the assembly plants. Although case studies could be undertaken using past difficulties with these decals, I have chosen to exclude them from the scope of this thesis and instead will focus attention upon the exhaust emission decals (henceforth referred to as simply emission decals).

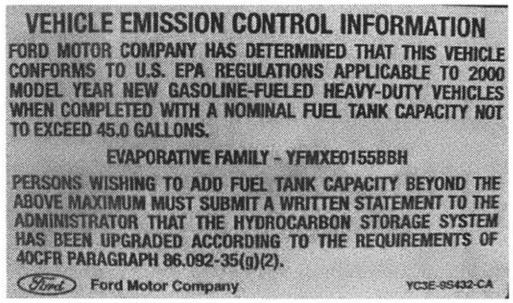


Figure 2. Ford evaporative emissions decal example, required on Federally certified engines greater than 8500# GVWR.

3.3. CARB – Title 13

Due to extremely poor air quality in parts of California, especially the Los Angeles metropolitan area, the U.S. EPA has granted California the right to promulgate their own set of emission regulations in Section 209 (a) of the Clean Air Act (CAA). The California Air Resources Board (CARB) based in Sacramento has set forth to create a generally stricter set of standards than that of the U.S. EPA in the California Code of Regulations (CCR) Title 13. At the same time, the U.S. EPA has strictly forbid other states from doing the same, in effect prohibiting a "third vehicle" certification. Individual states have been given the right via Section 177 of the same CAA to adopt the California emission regulations in full, if they so desire. Although there has been a bit of flux in the number of stating that have opted in, currently Massachusetts, New York, Vermont, and Maine[15] have adopted the California regulations and are commonly called "Green States" or "Section 177 States". This flux creates confusion in the ordering process and can result in properly labeled vehicles being sold in an incorrect market – thus leading to a recall campaign.

Current California emission standards are often referred to as 'LEV' standards[16]. The names of the standards when changing from Federal to California certification remain largely the same confusing the issue, while the numerical standards are different. The LEVI emission standards for light and medium duty vehicles are listed in Appendix A, pages 82 and 83.

Another change from Federal to California certification that can be noted in the table is the different weight class designations. For California certification, there are only Light-Duty Truck (LDT) 1 and 2's (<5750# GVWR). Heavy-Duty Engines (HDE's) are defined as engines being installed in vehicles greater than 14000# GVWR. This leaves a middle ground between LDT's and HDE's not seen in the Federal regulations. In California's regulations, this middle ground is inhabited by Medium-Duty Vehicles (MDV's). These are vehicle certified on the chassis dynamometers.

This leads to an interesting and sometimes confusing certification and labeling situation. The same vehicle can be Heavy-Duty Engine certified federally and Medium-Duty Vehicle certified for California (green states). The Federal emission decal would reflect the engine certification and would be installed on the engine itself. Ford chooses to install a second copy on the chassis. Meanwhile, the California emission decal would reflect the vehicle certification and would be installed on the vehicle chassis. It is even possible to create a '50 State' decal for this situation that could theoretically satisfy both regulatory agencies. However, this simplification for the assembly plant and vehicle pre-production planning (by reducing the number of decals) significantly increases the complexity for the design and release engineers. By meeting one user's requirement to reduce the number of possible decals, the part complication could potentially increase the possibility of errors being designed in.

3.4. Overseas Labels

Domestic manufacturers typically put less emphasis on the design and release of emission decals for foreign markets. This may in part be explained by the relatively small sales volumes in foreign markets or the much greater complexity domestically, but could also be explained in part by the relative lack of attention paid to the decal by those foreign governments. The U.S. EPA and especially California have been much more closely involved in recent years with emission decal issues and discrepancies, hence much more of the OEM's decal efforts are so concentrated. The author had the opportunity to track down several Ford contacts[17] in overseas markets who expressed understanding of the issues surrounding the design and release of North American emission decals, but clearly stated that the issues in their markets did not result in the same level of complexity.

For Ford, three design and release engineers cover all products for the U.S., California, Canada, and Mexico. The French language requirement of Quebec has been eliminated, but Spanish remains the sole language of the Mexican decal. One additional engineer (in a different department altogether) covers the Philippines (English), Columbia (Spanish), and Venezuela (Spanish) decals. The Taiwanese, Korean, and Chilean decals are designed by the divisions in that country and installed at the dealership.

Likewise, from the SDM International Business Trip in May 2003, the author generated an emission decal contact at Ferrari. While they make approximately 1/10 of 1% as many vehicles as a Big 3 manufacturer, the U.S. is one of their major export markets. An understanding of how a small manufacturer handled the labeling and whether the decal design and release presented difficulties for a specialty manufacturer were desired. In an e-mail from the Ferrari vehicle certification manager[18], the contact explained that they had a very small staff who worked on the certification and labeling of vehicles. They only produce two different engines (a V8 and a V12) also limiting the possible combinations in the 4000-4400 vehicles that they make per year. Prior to export, U.S. bound vehicles had the proper emission decal installed in a vehicle finishing area.

This exchange with Ferrari did help support one part of the hypothesis regarding the numerous information exchanges between key players who at most times do not understand the full emission decal design and release process. In the case of this small, specialty manufacturer, both the informational and process complexity is kept to a minimum. The informational complexity is held low relative to a major OEM because of the small number of engines, and therefore engine test groups to be certified. Process complexity is held low because only a small group of people is involved in certification and labeling. These few employees are thereby forced to know and understand the entire process, where a major OEM has further specialization that negatively impacts correct information exchange.

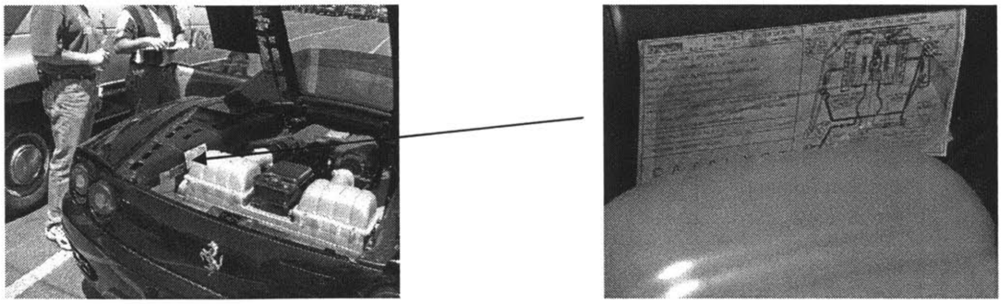


Figure 3. 2002MY Ferrari Spider Emission Decals.

Photos of 2002MY V8 Ferrari Spider taken 6/27/2003 in Flat Rock, Michigan. Note in the second photo the delamination of the decal. This could be the result of a design or installation error.

Based upon the information I received, this thesis focuses on the design and release of the most complicated emission decals, those for the U.S. EPA and CARB. It also focuses on the decals of the major domestic OEM's who have the largest range of vehicles and engines to certify and label.

As I conclude this chapter, hopefully it is clear to the reader that regulatory complexity plays a significant role in the difficulties encountered in the process of creating, releasing, and correctly installing emission decals. Regulatory intricacy will play a central role in each of the three System Dynamics case studies and accompanying models.

Chapter 4. Informational Complexity

Informational complexity is fundamental to the emission decals due to the increasing amount of information being regulated for inclusion on the decals, additional information voluntarily added by some manufacturers, and numerous choices available to design engineers, release writers, and installers. In the past ten years, new regulations such as National Low Emission Vehicle, Clean Fuel Fleet Vehicles, Tier II, LEVII, etc. have resulted in increased information being added to the emission decals. These increased requirements have taxed the system to the point where recall campaigns have steadily risen in the past few years. It is a premise of this thesis that poor systems understanding has led to a firm not always realizing how this increased complexity has increased the difficulty of getting the decals created correctly, released correctly, and installed correctly on the correct vehicles. Where the complexity has been recognized, very little has been done to improve the process due to the relatively low monetary costs and the relatively low rate of errors.

An understanding of the current informational complexity required of the emission decals is essential to gain insight on where the system potentially could break down, and as necessary background information to the System Dynamic models developed in Part III of this thesis. In this chapter, I will briefly describe the major portions of the emission decals, highlighting recent changes or confusion that has resulted due to the tremendous number of choices and increasing requirements.

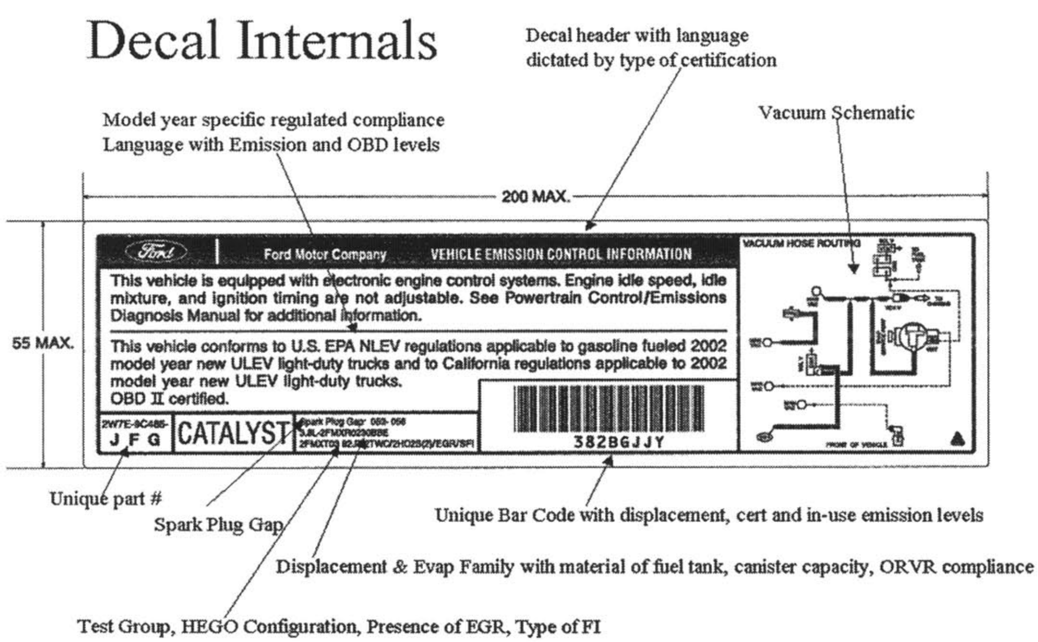


Figure 4. Breakdown and brief summaries of the different parts of the emission decal.

4.1. Detailed Description of Each Internal Component

4.1.1. Decal Header

The exact decal header, or the 'title' of each emission decal is prescribed by the corresponding regulatory agency. A typical location is shown in the figure above. For instance, the U.S. EPA and California both now use "Vehicle Emission Control Information" (aka VECI) for light-duty cars and trucks and "Important Engine Information" for HDE's. Previously there had been a third possible header for Federal certification only, "Important Vehicle Information" which was used for light-duty trucks while cars only used the VECI header. This unique header did occasionally create problems due to simple oversight or a misunderstanding on whether a vehicle was to be certified to car or truck emission standards. This may be hard to imagine, but minivans were often located in car development groups but certified to truck emission standards, while crossover vehicles such as the PT Cruiser (to be discussed later) blurred the boundaries between a car and a truck by being certified as a car for emission purposes but as a truck for fuel economy purposes. Increasing complexity resulted in a need for emission decal design and engineers to go beyond their stated job descriptions and learn nuances of certification regulations and teach those downstream in the process.

4.1.2. Unique Part Number

A unique part number is used for each emission decal to distinguish it from other parts in each company's engineering release system. In the example shown above and the one below, Ford uses a prefix-base-suffix part number convention. The prefix usually indicates the vehicle model that the part is to be used on and model year, but these parts all use the same prefix within a model year. Many of the tracking systems have developed that only use the suffix to track the part, resulting in confusion and a possible source of error if the same suffix is used with different prefixes in the same model year. The suffix (KKM in the example below) is often the only means by which the assembly plant distinguishes between multiple, slightly variant versions of the emission decal. This is not unlike the Year 2000 programming bug that used two digit codes for year before 2000. The Ford engineers are solely responsible for part number assignment.

Figure 5. Part number on a Ford emission decal. Ford has recently implemented a machine readable bar code of the suffix with an eye toward implementing bar code readers at the assembly plants to improve installation accuracy.

However, GM uses a different system in which designed decals are released against a specific Vehicle Identification Number (VIN). This is a unique number on each vehicle built. An example is shown below.

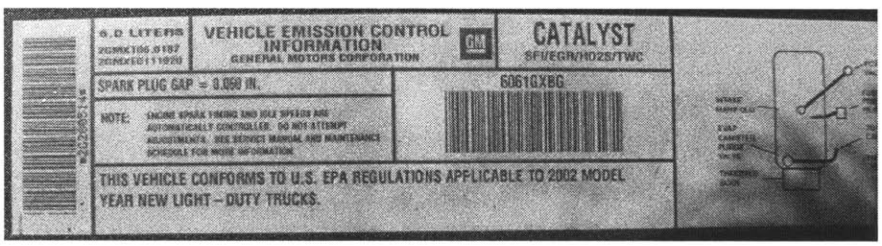


Figure 6. General Motors' emission decal example.

4.1.3. Spark Plug Gap

The spark plug gap information is the center of some debate. The regulations specify that "Engine tune-up specifications and adjustments...as well as other parameters deemed necessary by the manufacturer" also be included. Previously, Ford had interpreted this to mean that spark plug part number and spark plug gap should be included. This interpretation led to several campaigns to correct spark plug part numbers. When Ford first discussed removing the spark plug part numbers, there was tremendous pressure in the Ford Customer Service Division (FCSD) to continue providing the information. Ford does provided the part number information today in the Owner's Guide and not on the emission decal. For the 2004MY however, Ford did include spark plug gap information on the decal. GM, in contrast, did not believe that today's longer life spark plugs need to be gapped, so they did not feel it appropriate to include. This difference in judgment adds complexity to the Ford decals and potential rework and/or errors.

As complexity of the emission decals continue to increase, it becomes increasingly important to eliminate all possible sources of error. This self-inflicted complexity increase will be addressed again in Chapter 12 as a suggested change to the process.

4.1.4. Unique Bar Code

This piece of information was no longer required for the 2004 model year, but did cause significant difficulties for the engineering teams. The bar code was an 8-character bar code with human readable equivalent that indicated engine displacement in liters, Federal and California in-use emission levels, ignition frequency, presence of air injection, presence of EGR, and whether the vehicle was certified to Onboard Diagnostics Version 2 (OBDII). One character was left as a wild card so that each bar code was unique, even if all other information was the same. One engine family (or test group, more on this subject in section 4.1.6) could possibly use more than one bar code, but one bar code could not be used for multiple engine families. This presented tracking difficulties for the engineers who assembled the Application for Certification. Often more than one engineer would prepare the application for a particular engine size. This could result in the identical bar code being used in two different engine families if the application engineers did not communicate with one another. The decal design and release engineers developed software checks to verify that a bar code had not been used on another application that same model year after several 'near misses'.

Again, this level of complexity required the emission decal design and release engineers to go beyond their stated job descriptions and understand and study the differences between different engine test groups. This addition responsibility also had a cost – less of the emission decal design engineers' time was now available to actually do their advertised job function. This decrease in effective staffing will be addressed in the System Dynamic models of Part III.

462AGFFG

Figure 7. 8-character mandatory bar code unique to each engine test group.

<u>Bar Code Key by Character:</u>

1. Engine Displacement in Liters – 1st Character
2. Engine Displacement in Liters – 2nd Character
3. Certification Class
4. Alpha/Numeric Wild Card
5. Type of Combustion and Fuel
6. California Certification and In-Use Standards
7. Federal Certification and In-Use Standards
8. Emission Control Information – Air Injection / EGR / OBD

Figure 8. Character-by-Character key to the bar code. The example given in the preceding figure thus translates to a 4.6L LDT2 Otto-cycle gasoline-powered truck certified to full LEV certification and in-use standards for 50 States, w/o Air Inj., w/EGR & w/OBD

4.1.5. Displacement and Evaporative Family

This line on the emission decal (seen above) requires the engine displacement in liters and the evaporative emission family provided to the design and release engineers in the Application for Certification. These engineers who prepared the application received their information on this subject from the evaporative emissions group for whom the application was but a small part of their job. The evaporative emission family name includes information such as the carbon canister capacity for trapping fuel vapors, the material of the fuel tank, the weight class of vehicle, and whether the vehicle was certified to the Onboard Refueling Vapor Recovery (ORVR) regulations that were being phased in. This information comes to the design and release engineers in a package of information that has been signed by half a dozen people certifying (ISO compliant) that the information is correct.

What may not be immediately clear is that the design and release engineers are ultimately responsible for the information on the decals, even if the information provided to them is incorrect. While the decal design and release engineers are not tied directly to each program, they are expected to question information given to them if suspect and to proactively seek answers to questions that arise. With increasing informational complexity, the number of questions has risen substantially. Again, this reduces the 'effective staffing' available to actually design and release the decals themselves. Also important in this discussion of proactively questioning all information provided to them, are the issues of time on the job and process maturity of the engineers. In the System Dynamics models to follow, time on the job results in an "S-curve" of work quality where work quality rises substantially as time on the job increases but flattens with diminishing returns as time passes. This "S-curve" of quality can be thought of in several ways: a) inexperienced employees gain insight and experience in how to do their jobs better thereby eliminating misunderstandings or oversights and b) as employees gain experience they also develop their formal and informal information exchanges, i.e. they know who to approach to resolve a question quickly and efficiently.

Figure 9. Engine displacement, engine test group, and evaporative family information.

<u>Evaporative Family Key by Character:</u>

1. Model Year
2. Manufacturer – 1st Character
3. Manufacturer – 2nd Character
4. Manufacturer – 3rd Character
5. ORVR Certification Level
6. Canister Working Capacity – 1st Character
7. Canister Working Capacity – 2nd Character
8. Canister Working Capacity – 3rd Character
9. Canister Working Capacity – 4th Character
10. Evaporative Emission Standard Level
11. Type of Fuel Tank – Steel or Plastic

12. Combination of Weight Class and Evaporative Emission Standard Level

Figure 10. Character-by-Character key for the evaporative family name. Using this key, the evap family name in the preceding figure is for a 2003MY Ford gas LDV or LDT w/160 g of canister, plastic fuel tank, meeting enhanced evap & ORVR standards.

4.1.6. Auxiliary Information

This line on the emission decal contains such information as the engine family (sometimes called the engine test group), configuration of catalysts in the exhaust system, the presence or absence of EGR, and the type of fuel injection used.

Engine Family/Test Group Key by Character:

1. Model Year
2. Manufacturer – 1st Character
3. Manufacturer – 2nd Character
4. Manufacturer – 3rd Character
5. Type of Vehicle Certification
6. Engine Displacement in Liters – 1st Character
7. Engine Displacement in Liters – 2nd Character
8. Engine Displacement in Liters – 3rd Character
9. Engine Displacement in Liters – 4th Character
10. Weight Class
11. Certification and In-Use Standards
12. Sales Area – Federal/California/50 States

Figure 11. Engine Family/Test Group Key Character-by-Character. Thus the example given above in Figure 9 is for a 2003MY Ford 50 State certified 4.6L LEV LDT2.

Of particular interest is the catalyst configuration information. A chart used by Ford to distinguish catalyst configuration is included in Appendix B to illustrate the numerous choices available. Regulation and the Society of Automotive Engineers (SAE) cover any abbreviation or acronym used.

2TWC,TWC/2HO2S(2)/EGR/SFI

Figure 12. Catalyst configuration, Oxygen sensor configuration, Presence of EGR, and Type of fuel injection.

It is not uncommon for the decal design and release engineers to have errors in the information provided to them. As was stated previously, it is the ultimate responsibility of the decal engineers to provide correct information on the decals, even if information provided to them is incorrect. This could be viewed as a disconnect with engineers not intimately involved in the program, but rather a specialist providing a service to each program, being ultimately responsible for program specific content. One of the improvement ideas suggested at the end of Chapter 2 was the automatic linking of input information into the decal, thereby eliminating a human transcription of data. This automatic feed would place the onus of those providing data to meet timing and provide accurate information, rather than the onus being placed on the decal design and release engineers to vouch for accuracy and recover any time slip in the process.

This automation would require a significant amount of resources to develop by a team with a systems understanding of the certification, decal, release, and installation processes. The magnitude of this undertaking would almost certainly not meet the requirements for a 1-year return on investment.

4.1.7. Vacuum Schematic

A schematic of vacuum lines is required by regulation to be included either as a part of the emission decal or as a separate label. All manufacturers investigated currently have the vacuum schematic as part of the emission decal, although some apparently separate the schematic from the text of the reminder of the decal for packaging purposes. A point of interest is that many functions previously actuated by vacuum lines are now controlled electronically, bringing the necessity of requiring the schematic into question. The schematics are forwarded to the certification group by the engine design groups who are very busy and often do not focus much attention on the schematic. Further, on the heavy-duty engine side, it is not uncommon for one vehicle/engine combination to have multiple schematics resulting in multiple decals depending upon use. One possible scenario is that a larger fuel tank requires more carbon canisters, and in turn these extra canisters must be shown on the schematic. This one piece of required information has resulted in quite a few decal correction efforts. There is currently the investigation of an incorrect schematic at one OEM that was signed off several times by the responsible engine group.

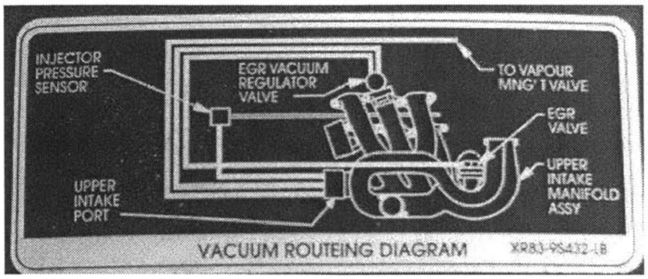


Figure 13. Jaguar vacuum schematic example. This example is separated from the text portion of the emission decal, which is allowable by regulation.

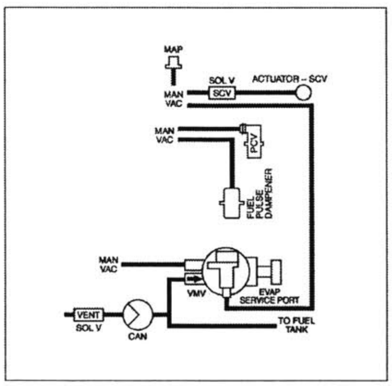


Figure 14. Ford vacuum schematic example. This schematic is attached to the text portion of the decal, eliminating one potential source of installation error.

4.1.8. Compliance Language

The compliance language is the highly regulated text that is designed to provide an "unconditional statement of compliance" with the applicable regulations. Many possible combinations of text exist, especially for those large OEM's that certify a wide range of vehicles. In addition to the straight-forward basic text, special phrases apply for such things as:

- Clean Fuel Fleet Vehicle Status
- Type of Certification Fuel (other than gasoline)
- Level of OBD Certification
- Heavy-Duty Engines Certified in a Vehicle to Light-Duty Truck Standards
- Frontal Area and Weight Limits for Stripped Chassis and Cut-Away Certifications (numerical limits are required)
- Compliance with applicable California Health and Safety Codes (HSC's)

The following are examples of extreme cases of the required compliance language:

1. This vehicle conforms to U.S. EPA regulations applicable to 2004 model year new light-truck trucks.

2. This engine conforms to U.S. EPA regulations applicable to 2004 model year new ULEV heavy-duty gasoline fueled engines, and meets all of the applicable requirements of 40 CFR Part 88. This engine is certified for use in all Federal heavy-duty vehicles. This vehicle/engine conforms to California regulations applicable to 2004 model year new ULEV medium-duty vehicles (GVWR of 8501-14000 pounds) with heavy-duty Otto-cycle engines and to U.S. EPA regulations applicable in California. OBD II certified.

It is not uncommon for a large OEM to use a multitude of different compliance statements as conditions warrant. For instance, internally, Ford produces a multi-page document every model year prior to the first certification of the model year. This document is designed to contain all the possible compliance languages combinations for the upcoming model year. While a good goal, this has been found to be impracticable due to changing regulatory conditions, new developments, special agreements with regulatory agencies, etc. To help limit confusion, several years ago Ford tried to tie compliance language to particular anticipated applications prior to the model year, with limited success.

It cannot be stated frequently enough that even though the emission decal design and release engineers are provided numerous compliance language choices to select from, it is their ultimate responsibility to select the correct compliance language for the application in question. If they determine that none of the provided compliance language selections are appropriate, then they are expected to raise the issue to the regulatory interfaces. This has happened several times in recent memory – once when Federal regulations were not yet implemented for ethanol flexible fueled vehicles and once when the language as written did not make sense for natural gas fueled vehicles. These additional job responsibilities of the decal design and release engineers require greater certification and systems understanding than was previously necessary. However, it also reduces 'effective staffing' and can hasten job dissatisfaction if their efforts are not realized.

4.2. Ford Econoline Example

To better illustrate the complexity resulting from compliance language deviations, listed below are the decals released for the original certification of the 2002MY Ford Econoline vans. These vans are all produced at one assembly plant in Lorain, Ohio. As you can see from the list, the Econolines required 31 different decals at the same time! Note the complexities in the descriptions of which decals are required on which vehicles. This is but one vehicle line and one assembly plant. For a major OEM, it is not unheard of to have 150-200 active decals at one time, with a total of 250-300 being released every model year. These additional decals are required due to Post Job #1 changes (Job #1 is the initial launch of a vehicle line each model year, Post Job #1 means subsequent changes to that vehicle line within the same model year)– typically to reduce costs and/or meet more stringent emission standards. Some assembly plants, which see the decals as just another part, do not understand the rationale behind the multiple variations of emission decals necessary to comply with regulations, leading to some contention, which will be addressed a bit later.

Econoline (Lorain, OH) – 31 Different Active Emission Decals at One Time

4.2L

- *JBC (Federal/Canada less Clean Fuel Fleets, E-150 Payload Pkg #1)*
- *JLZ (Federal/Canada less Clean Fuel Fleets, E-150 Payload Pkg #2 and #3 &E250 3.73 axle)*
- *JSM (Federal/Canada less Clean Fuel Fleets, E-250 4.09 axle)*
- *JJD (Federal/Canada less Clean Fuel Fleets, E-250 Stripped Chassis & Cut-Away)*
- *JJK (Mexico)*
- *JTK (California plus Clean Fuel Fleets, E-150 Payload Pkg #1)*
- *JMK (California plus Clean Fuel Fleets, E-150 Payload Pkg #2 and #3 & E250 3.73 axle)*
- *JST (California plus Clean Fuel Fleets, E-250 4.09 axle)*
- *JPH (California plus Clean Fuel Fleets, E-250 Stripped Chassis & Cut-Away)*

4.6L

- *JMH (50S & Clean Fuel Fleets)*

5.4L Gas Light-Duty

- *JAZ (50S/Canada/Federal Clean Fuel Fleets <=8500# GVWR)*
- *JSH (50S/Canada/Federal Clean Fuel Fleets >8500# GVWR, <10000# GVWR, HDT cert as LDT)*
- *JPK (Mexico LDT & HDT as LDT, <10000# GVWR)*

5.4L Gas Heavy-Duty

- *JYT (Federal/Canada/Federal Clean Fuel Fleets, 35 or 37 gallon fuel tank, 10001-14000# GVWR)*
- *JUP (Federal/Canada/Federal Clean Fuel Fleets, 55 gallon fuel tank, 8501-14000# GVWR)*
- *JYU (Mexico, 35 or 37 gallon fuel tank, 10001-14000# GVWR)*
- *JAH (Mexico, 55 gallon fuel tank, 8501-14000# GVWR)*
- *JMM (California Incomplete and 50S/Federal Clean Fuel Fleets LPO use only, 35 or 37 gallon fuel tank, <=14000# GVWR)*
- *JJY (California Incomplete and 50S/Federal Clean Fuel Fleets LPO use only, 55 gallon fuel tank, <=14000# GVWR)*
- *JGB (50S/Canada/Federal Clean Fuel Fleets >14000# GVWR)*

5.4L NGV

- *JGT (U/8500# GVWR 50S & Canada LDT)*
- *JLP (O/8500# GVWR 50S & Canada LDT)*
- *JBA (O/14,000# GVWR 50 States HDT)*

6.8L

- *JHC (Federal/Canada/Federal Clean Fuel Fleets, 35 or 37 gallon fuel tank, 8501-14000# GVWR)*
- *JDA (Federal/Canada/Federal Clean Fuel Fleets, 55 gallon fuel tank, 8501-14000# GVWR)*
- *JPZ (Mexico)*
- *HPM (California Complete <=14000# GVWR)*
- *JDH (50S/Canada/Federal Clean Fuel Fleets >14000# GVWR)*
- *JBD (California Incomplete and 50S/Federal Clean Fuel Fleets LPO use only, 35 or 37 gallon fuel tank, <=14000# GVWR)*
- *JKS (California Incomplete and 50S/Federal Clean Fuel Fleets LPO use only, 55 gallon fuel tank, <=14000# GVWR)*

7.3L Diesel

- *JSA (California, 8501-14000# GVWR)*

Table 1. 2002MY Econoline emission decal usage chart.

Increasing informational complexity has resulted in complications to the emission decal design and release process. Many of the divisions of labor were not designed with the current level of intricacy anticipated. It has increasingly fallen upon the design and release engineers to sort through discrepancies, oversights, and information that 'does not feel right'. Increased time on the job and process maturity have resulted in higher work quality and a higher percentage of initial errors being caught in the checking process.

As more background is required of the design and release engineers as they are expected to undertake additional information checking tasks, the 'effective staffing' or person-hours available to actually design and release the decals has been reduced. Further, the stress of taking on additional tasks with little or no recognition tends to increase stress and speed the search of these engineers for other job assignments, thereby lowering average time on the job and in most cases lowering process maturity of the key players in the process.

Chapter 5. Process Complexity

Transitioning from informational to process complexity, this paper first looks at the accuracy of the process through traditional six-sigma statistics. Although the process accuracy appears to be very good, one needs to be reminded that even one error can potentially result in a multi-million dollar recall campaign if not caught in the checking process. Looking at some of the process complexity involved in late changes to certification standards, locations, and sizes, as well as taking into account disagreements on timing and the use of placeholder decals, it is easy to see how the 'effective staffing' is sacrificed by not having firm agreements and standards in place. This demand for more and more from the process participants, in a smaller time window while using a process not designed for Post J#1 changes, is a dangerous situation that could potentially result in escalating recall campaign costs.

5.1. Productivity and Accuracy Numbers

The number of emission decals released by a major OEM such as GM, Ford, or DaimlerChrysler is very similar. They each reported releasing 225-300 emission decals per model year for the North American markets. For Ford, with three engineers handling the design and release, this averaged out to approximately 87.5 decals per person per year. Assuming approximately 220 workdays per year after holidays, vacations, etc. and an 8-hour workday, this calculation results in 1760 hours worked per person per year. Dividing by the 87.5 decals to generate a base productivity value, this means that each Ford engineer is design and releasing a decal every 20 hours or 2 per week. This work, however, is not evenly spaced throughout the year because many of the vehicle launches are bunched together. This bunching of work creates a backlog of work during the launch season. This trend is seen in the System Dynamics models and can be aggravated by policy changes, as we will see in the models.

Decal process accuracy was touched upon earlier in Chapter 3 when it was stated that over a 5 year period for one major OEM, approximately 160,000 vehicles were recalled out of an approximate North American sales total of 20 million vehicles. This translates into a 0.8% rate of recall. However, only 2752 vehicles were recalled due to a design error on a decal. This translates into a 0.014% design error rate. Using Defects Per Million Opportunities (DPMO) measurements typically used in six-sigma and conservatively estimating that each decal contains twelve opportunities for a design error, only one decal design error was subject to recall in five years or approximately 1250 decal designs. This calculates out to a DPMO of 66.67 – or a short-term 5.3 Sigma! This is a tremendously accurate process when compared with other automotive processes. In fact, the majority of recalls have been attributed to communication breakdowns, installation difficulties, or a failure to meet requirements above and beyond regulation. But the potential for an error being designed in and not caught is still a possibility and needs to be accounted for.

5.2. Locations

According to the regulations, the decals "shall be affixed in a readily visible position in the engine compartment…in such manner that it cannot be removed without destroying or defacing the label. The label shall not be affixed to any equipment which is easily detached from such vehicle."[19] Several examples are shown in the accompanying pictures.

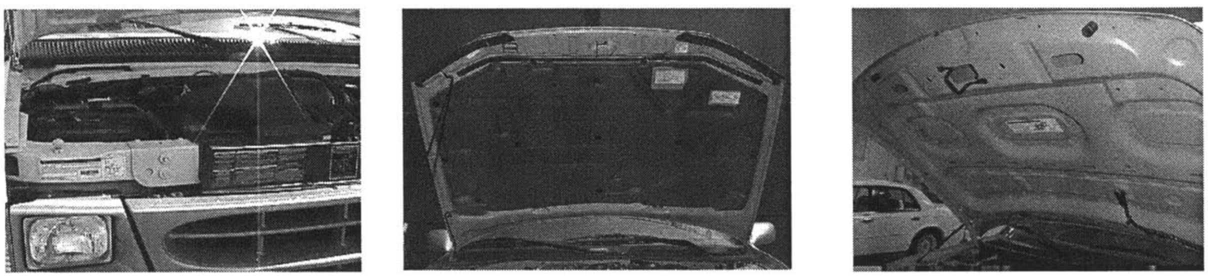


Figure 15. Examples of various possible emission decal underhood locations.

This is quite vague and left to the discretion of the various manufacturers. One good question is "what constitutes easily detached?". Everyone has his or her own ideas. Each vehicle can be assembled and disassembled, but what is easy for some may be exceedingly difficult for others. The Ford Office of General Counsel (OGC) has in the past taken the position that any part that requires tools to be removed is not easily detached. This left hoods, radiator support cross-members, and sight-shields attached with a method other than Velcro and pushpins as prime locations. However, California started to take exception to any decals being installed on any type of sight-shield, no matter how it was attached. Since the courts have given the regulatory agencies wide latitude to interpret their own regulations, Ford OGC shifted their position to a more conservative one, asking for emission decals to be transitioned away from sight-shields altogether. However, whether it was due to a change in OGC personnel or a relaxation on the part of the regulatory agencies, this move away from sight-shields has stalled, with some packages remaining in that location.

The ambiguity over what are acceptable locations has in the past caused significant rework and contributed to a significant recall campaign that will be investigated further in Chapter 9. This ambiguity also results in many iterations and a time commitment on the part of the decal design and release engineers. This is time away from the actual design and release activities and results in a lower 'effective staffing' level. The stress that can arise from being pulled in many different directions can also play a role in increasing the turnover of personnel.

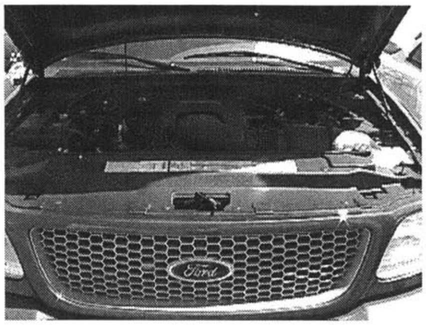


Figure 16. Emission decal shown on a sight shield for the Ford F-150.

5.3. Sizes

The size of the emission decals is another source of ambiguity. Two examples are shown below.

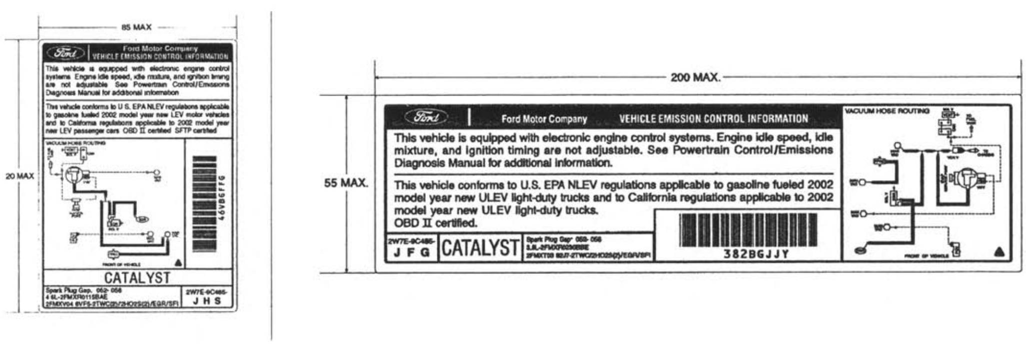


Figure 17. Just two possible sizes for the emission decals. Possible shapes are essentially limitless.

The regulations state that the decals must the "readable from a distance of 18 inches". "Readable for whom?" is a viable question. This has also left much to the discretion of each company. However, the agencies have provided a font lower limit of 3/32nds of an inch for the header and compliance language. Ford has adopted a minimum footprint approach. For packaging purposes, the Ford design and release team tries to narrow down location choices for each program (with limited success) and gives a minimum square millimeter requirement in order for the decal text to maintain legibility. One drawback to this approach is that decal sizes or locations may have to change if new regulatory requirements or agreements result in more text being added to the decal. This in fact has happened on more than one occasion and has resulted in rework activity.

This rework activity takes time and resources away from the actual design and release of emission decals. This is an additional requirement of the design team and often takes a significant amount of resources to optimize both size and location for each product line.

5.4. Late Changes

Late changes are currently very common due to late certification changes or new direction from upper management. As was alluded to previously, many of the late changes are designed to reduce the cost of the vehicle being built or to allow the vehicle to be certified to more stringent emission standards. This change of emission standards is due in part to complex calculations that determine the average emission standards to which all an OEM's vehicles meet in a given model year. Each OEM is legally bound to meet certain fleet average requirements via NMOG credits and NOx credits with the limited ability to pull-ahead banked credits from one model year to the next. This is complicated by a rich interaction of factors that affect the sales mix including styling, reviews, fuel prices, etc. Only some of these factors are under the direct control of the OEM's. The emission standards to which a particular vehicle will get certified to in a given model year is a bit more fluid than one might at first believe. For instance, if a NOx credit shortfall is projected in a future model year, an OEM might look at opportunities to reduce NOx emissions across any and all vehicle lines. Some of the opportunities may be current model year programs for which the most accurate data exists. If this were the case, additional calibration, certification, and emission decal design and release efforts would probably be required in very short order to meet this changed directive. This 'fire-fighting' activity was mentioned briefly in Chapter 2 and takes time and attention away from improving the process at hand.

5.4.1 Design Structure Matrix

I have included a Design Structure Matrix (DSM) below that illustrates some of the rework necessary in the circumstance of late change. (The DSM is a project management tool that is taught as part of the SDM curriculum. Past Co-Director of the SDM program, Professor Steven Eppinger, has done much of the current work in the area of expanding the use of DSM's to the project management arena.) This DSM was first started by the author as a deliverable in Professor Eppinger and Professor Lyneis' SDM class, System and Project Management, but was expanded for use in this paper. The first figure illustrates the emission decal design and release process as is. In effect, the development process, read line item by line item, must loop back to a previous line item when a late change is required. Note that every number above the diagonal is a possible iteration causing rework and the different numbers are a way of classifying the likelihood of the event (in this case the numbers serve as a 'probability of repetition', which means that the numbers reflect the probability of one activity causing rework in another).

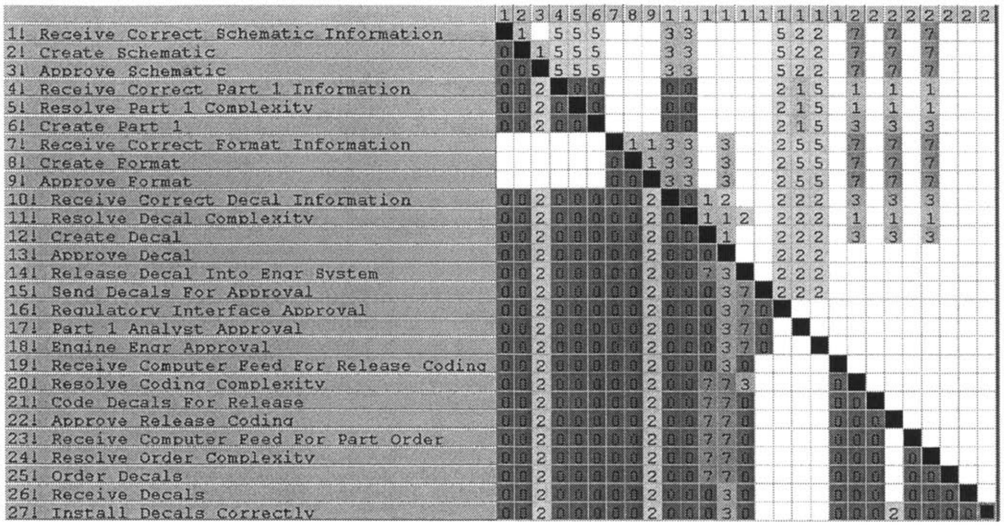


Figure 18. DSM of the emission decal process before partitioning.
Note the high degree of possible iteration.

The second figure is the DSM after partitioning showing iterative blocks. In this case, note the high degree of iteration and cooperation required of the design and release engineers in the large center block. This partitioning suggests that these engineers need to stay in constant contact with the Part 1 analysts, release writers, and assembly pre-production teams to help resolve Part 1, release coding, and ordering complexity issues respectively. A failure to work interactively could result in more errors.

Another key learning point from DSM is that as the matrices reorder and group events, the goal is to eliminate, or at the very least shorten, the rework circuits. In Figure 19, the grouping of events in blocks highlights the need for increased teamwork. There are five such blocks if you look closely at the following figure. The emission decal design and release engineers would be required to belong to all five sub-teams suggested by the iterative blocks of the DSM. Multiplying these five sub-teams by the numerous product lines would greatly increase the time commitment required for each design and release engineer.

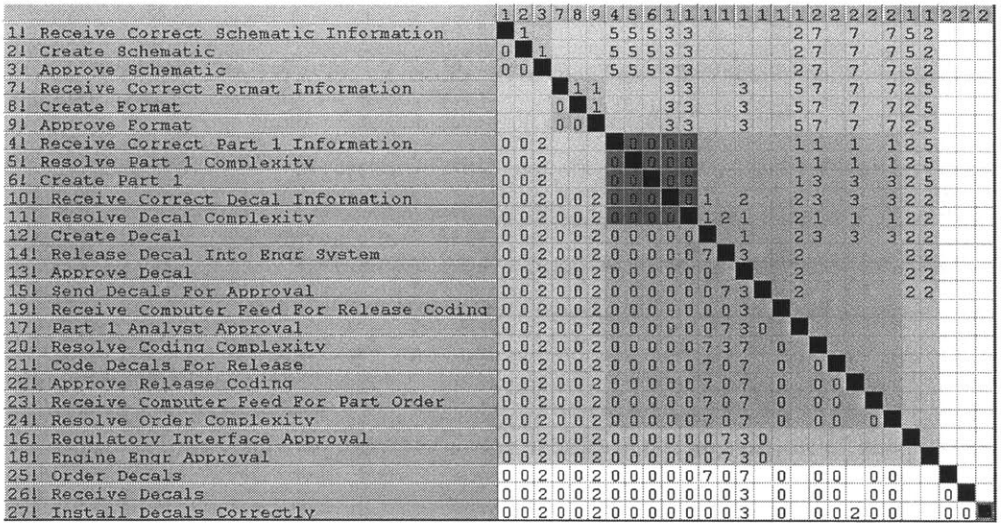


Figure 19. DSM after partitioning. Note the high degree of teamwork and cooperation necessary to limit the detrimental effects of rework. This center block could comprise core members of a heavyweight team structure - to be discussed further in section 6.6.2.

As you can see, the DSM addresses the dynamic consequences of iteration. It is capable of demonstrating the results of iterations, but does not represent the underlying processes that drive it. To look at the underlying processes of the emission decal process, we will later use formal System Dynamics modeling.

5.5. Timing Issues

There are many issues that affect the timing of the release of the emission decals for each vehicle program. There is often wide disagreement within each OEM as to when the real emission decals should be delivered each model year. These disagreements could be viewed as conflicting user requirements.

5.5.1. 1PP versus Integrated Build

For instance, Ford product development timing calls for all parts to be released by 1PP, a pre-launch gate that occurs several months before the Job #1 launch. However, due to the timing of other milestones in the development process, this is usually not possible. This leads to internal disagreements and requires time to manage the resulting discussions and meetings. With the support of their direct management, the current design and release team works to meet integrated build timing. Integrated build is a date much closer to launch than 1PP when the assembly plants ramp up the line to full production. Prior to this time, any vehicles built for the new model year are typically done in batch jobs. Any quarantine of vehicles to await decals or installation of Exemption Labels, described in the next section, is relatively minor up to this integrated build date.

However, most of the assembly plants still believe that a part is a part, and that all should meet corporate timing and be available by 1PP. This disagreement results in numerous phone calls, meetings, e-mails, even trips to assembly plants to placate angry vehicle build teams that take time and attention away from the design of accurate emission decals. The disconnect continues between Product Development and Vehicle Assembly in large part because they are in different 'chimneys' and report to different Vice-Presidents. Time wasting actions continue because the relatively simple issue does not get forwarded up through the chain of command to a level at which it can ultimately be resolved.

A Critical Path Method (CPM) diagram is included to help illustrate the timing of events leading up to the decal release.

CPM Key

1. Receive Correct Schematic Information
2. Create Schematic
3. Approve Schematic
4. Receive Correct Part 1 Information
5. Resolve Part 1 Complexity
6. Create Part 1
7. Receive Correct Format Information
8. Create Format
9. Approve Format
10. Receive Correct Decal Information
11. Resolve Decal Complexity
12. Create Decal
13. Approve Decal
14. Release Decal into Engr System
15. Send Decals for Approval
16. Regulatory Interface Approval
17. Part 1 Analyst Approval
18. Engine Engr Approval
19. Receive Computer Feed for Release Coding
20. Resolve Coding Complexity
21. Code Decals for Release
22. Approve Release Coding
23. Receive Computer Feed for Part Order
24. Resolve Order Complexity
25. Order Decals
26. Receive Decals
27. Install Decals Correctly

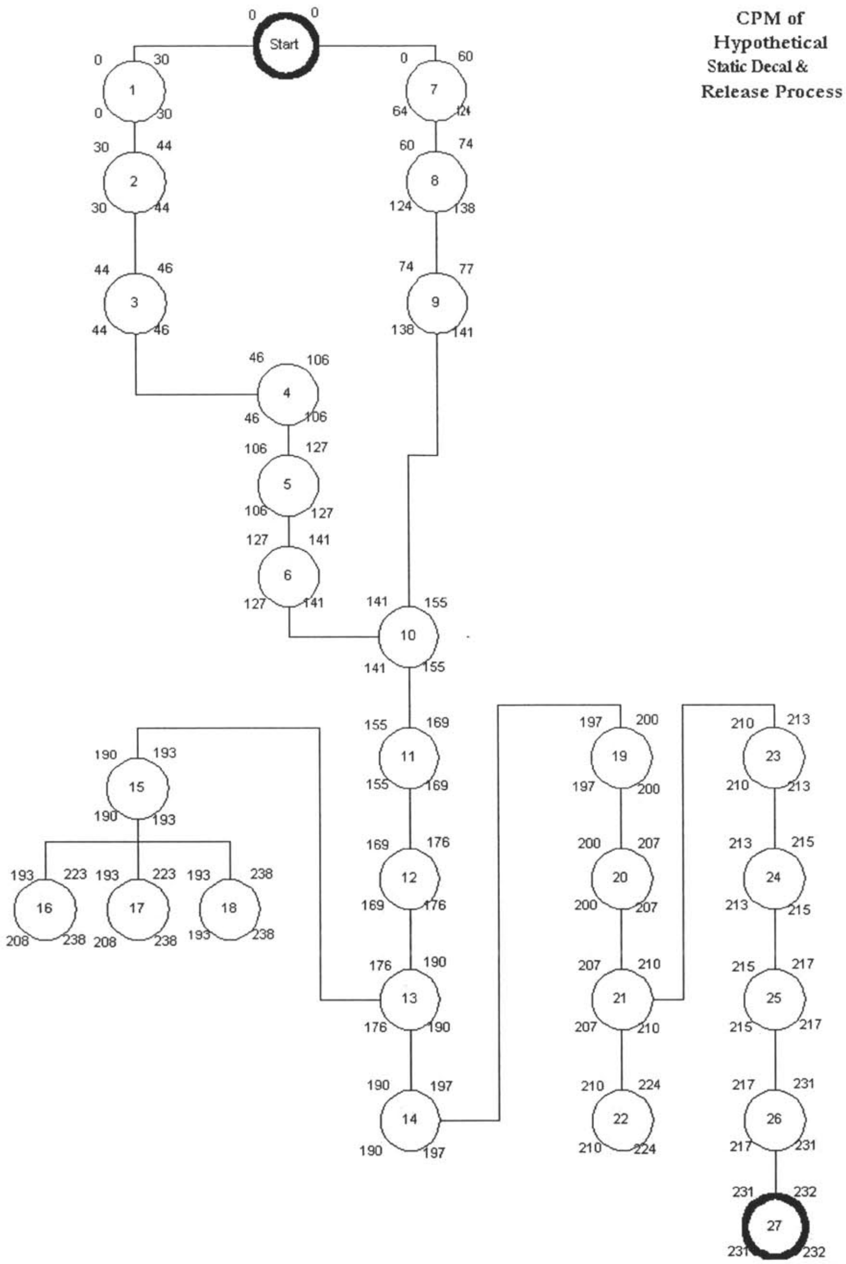


Figure 20. CPM of the hypothetical static emission decal process. Note the sequential nature of most tasks and the general lack of slack in the system.

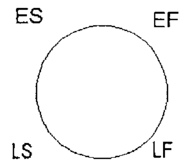


Figure 21. Basic layout of CPM timing information.

CPM Basics

- Earliest Starting Time ES = Largest Earliest Finish Time (EF) of predecessors
- $ES_i = \max_k \{EF_k \mid k \text{ precedes } i\}$
- Latest Finishing Time LF = Smallest Latest Starting Time of successors
- $LF_i = \min_k \{LS_k \mid i \text{ precedes } k\}$
- $Slack_i = LF_i - EF_i = LS_i - ES_i$
- Criticality = Slack/Task Duration [%]

Table 2. CPM basics from MIT SDM Operations Management course taught by Professor Thomas Roemer.

An important take-away from the CPM approach is the lack of slack in the process. The highly sequential process leaves almost no slack time in any one individual event. If one event does not meet timing, timing of the entire process slips as a result. As information changes timing invariably slips; the result is either a slip in overall timing if work slows down to ensure accuracy, or quality suffers as events are hurriedly completed to meet milestone dates.

However, a CPM also has shortcomings. While it is able to illustrate the sequence of events for which timing is critical, it is a traditional project management tool that describes events in a static manner with only duration estimates and precedence relationships describing the sequence of tasks. System Dynamics will help us to overcome the static nature of traditional tools.

5.5.2. Certification Received

As was covered previously, it is illegal for vehicles to be shipped from the plant with an emission decal installed prior to certification being complete. An 'Exemption Label' can be installed directly over the emission decal if the vehicle is not yet certified (or in lieu of the decal altogether). This Exemption Label is a vehicle-specific label that indicates that the vehicle is not yet certified. A different group than the emission decal design and release team coordinates the use of exemption labels, permits their use on a limited basis, and keeps detailed records that track each exemption label by unique Vehicle Identification Number (VIN). But the potential for vehicles with readable emission decals getting out the door prior to certification or vehicles not being retrofitted once it is actually certified is a potential jeopardy to the manufacturers. This is a fineable offense and it is standard for the finger pointing to go back to the design and release engineers, even if everything is designed correctly and released into the engineering system correctly.

Many of the vehicle build teams try to demand decals to support all their pre-production builds. First, these are activities for which time is not budgeted. Secondly, it presents an opportunity for uncertified vehicles to get in the field with a decal claiming certification. This is clearly against regulation. If the design engineers release a decal into the engineering release system and it proceeds mistakenly into the field, the design engineers are responsible. Therefore, they try not to release for uncertified builds, but this creates great hardship and misunderstanding between Product Development and Vehicle Assembly. Each disagreement tends to get repeated several times each year with different vehicle lines and continues to take time away from the process of insuring accuracy. As turnover happens in each position, the process tends to repeat. The issue never gets elevated to a level where it can get definitively resolved. These unresolved conflicts do repeat and add aggravation and complexity across vehicle lines.

5.5.3. Use of Placeholder Labels

Placeholder decals also tend to be a contentious issue within OEM's. A placeholder decal is in effect a 'dummy' decal that is designed to help finalize underhood locations, and to have a part released into the build sheet system to alleviate the deluge of phone calls, e-mails, meetings, and other interactions designed to gain a better understanding of why the decals are behind corporate timing. However, these events usually put the releases further behind in a vicious circle, or reinforcing loop, as it is described in System Dynamics.

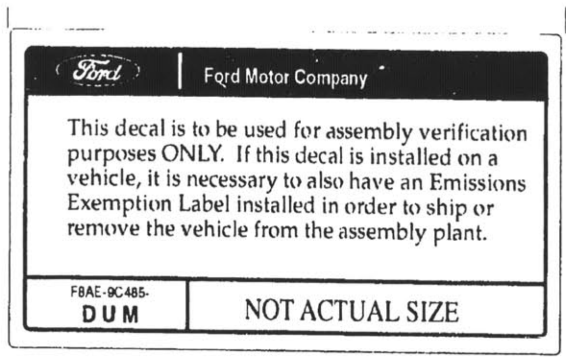


Figure 22. Example of placeholder emission decal designed and infrequently used by Ford.

Some programs like to have a part, any part, released into the system. However, the number of decals eventually needed is not typically known, nor is the one-size-fits-all 'dummy' decal necessarily the same size as the eventual product, nor can vehicles be shipped from the assembly plants with this placeholder decal. It can be quickly released for a vehicle line, however, and does tend to alleviate some pressure from the design and release engineers. Past management has liked the placeholder decals because they also tended to reduce the internal adverse notoriety of being late to release by corporate timing. But most programs choose not to utilize these placeholders. Clearly, there is no standard across all product lines.

In summary, the complexity of the process is driven by a poor systems understanding of how changes can affect the entire certification, decal design, release, and installation process. This drives down from a high level where late changes are routinely made to reduce costs or produce additional credits. Likewise, the non-standardization of emission decal locations, sizes, and use of place holder decals unnecessarily complicates the process and takes valuable time and attention away from the increasingly difficult task of deciphering the regulatory and informational complexity. These complexities drive the importance of this thesis in studying the emission decal design and release process and the use of System Dynamics to highlight how some of these complexities can affect recall costs.

Chapter 6. Ambiguity, Confusion, and Indifference

This chapter is designed to look at some of the confusion surrounding emission decals caused by recent regulatory changes, differences in organizations, and general indifference to designing a 'simple sticker'. These are important issues to discuss because of the tremendous impact they can have on taking what many believe should be a simple process, and explaining how the process has mushroomed beyond what it was intended for. These are important building blocks to affecting real change and improving the beleaguered reputations of all those involved in the evermore complicated process.

6.1. Crossovers

Crossovers are a class of vehicles that have been gaining in popularity in recent years due to a number of issues including the popularity of 4WD cars (Subaru has taken the lead on this issue), popularity of small Sport Utility Vehicles (SUV's) such as Toyota RAV4 and the Ford Escape, unstable fuel prices due to conflict in the Middle East, and a shift in public sentiment away from large SUV's. Crossovers are generally defined as vehicles that blur the boundaries of what is a car and what is a truck, hoping to appeal to new consumer sentiment. These products have also helped to blur what is a car and what is a truck for certification and labelling purposes as well. Federally, cars have the phrase "new motor vehicles" in the compliance language while small trucks use the phrase "new light-duty trucks". Any incorrect usage is recallable and subject to fine. The issue of potential fines were addressed previously in Chapter 2.

The U.S. EPA requires that an OEM's Truck Corporate Average Fuel Economy (CAFÉ) be at least 20.7 miles per gallon (mpg). This had been the matter of much debate during President G. W. Bush's administration. Because large trucks often with poor fuel economy generate considerable profits for each company, it is in their best interests to find small trucks that can raise the truck CAFÉ numbers. This is where crossovers can be very important to a company beyond just their direct buyers. Companies try to find ways to classify crossovers as trucks.

In the past, minivans were possibly the biggest confusion. Although certified as a light-duty truck, Ford often had the minivans in the car groups. However, taking it a step further, DaimlerChrysler introduced the PT Cruiser several years ago. After much debate, this vehicle was certified as a passenger car, but is considered a truck for fuel economy purposes per 49 CFR 523.5[20]. As crossover numbers increase, this puts another pressure on the decal design and release engineers to go beyond their stated job descriptions and to become regulatory experts who can critically evaluate all information given to them. This takes time and training, thereby reducing the 'effective staffing' actually designing and releasing emission decals. Increasingly, the emission decal design and release engineers are serving as error checkers for the entire certification process.

6.2. National LEV

National LEV was a program instituted by the U.S. EPA to provide an incentive for OEM's to offer lower emission vehicles Federally in the Northeast Trading Region (NTR) of the United States, comprising most of the New England. Part of the rationale was that OEM's could offer vehicles designed to meet California's more stringent emission standards in these NTR states. It could be argued that this may provide benefit for a small manufacturer so that they do not need to certify different packages, but in general the cost of developing and certifying a vehicle to be in compliance with California regulations was higher, generally in the cost of the catalyst where the precious metals of platinum, palladium, and rhodium used to chemically react with engine out emissions to lower tailpipe emissions of NMHC, CO, and NOx. A large volume manufacturer often chose not to certify all products as National LEV. It might be that an automatic transmission vehicle could meet National LEV emissions while a manual transmission could not. Or vehicles under a certain weight class could meet the stricter standards; while it would be too costly to have the heavier vehicles comply. In these instances, certification and emission decal complexity actually increased. New compliance language text was required on National LEV vehicles before the EPA decided[21] that these vehicles should be labelled exactly as California-certified vehicles were. In this and other cases (noticeably alternatively fueled vehicles) emission regulations did not stay ahead of the technical curve. Because new circumstances required working with the regulatory agencies often through a joint lobbying group such as AAMA (American Automobiles Manufacturers' Association), time and effort was required of the engineers further taking their attention away from the actual design and release of decals. It has been argued that increasingly the emission decal design and release engineers are actually transitioning into a hybrid role of certification analyst and design and release engineer. It has become paramount that they stay up-to-date with all current and proposed certification regulations so that errors can be minimized.

6.3. Tier I vs. Tier II (Federal)

Chapter 3 of this paper showed the Federal Tier I emission standards that have been in place for LDV's, LDT's, MDV's, and HDE's. It should be clear that the numerical standards applicable to the various weight classes have been substantially different. However, in an effort to further reduce air pollutants, the EPA has promulgated Tier II emission standards to begin in the 2004 model year. These are included in Appendix A, page 82 for reference and will be revisited in Chapter 8 as we discuss the 'coordinated change'.

Part of the rationale behind Tier II is to treat all vehicles less than 8500# GVWR that were formerly classified either as light-duty vehicles or light-duty trucks (1-4) identically. Regulators were concerned with a shift away from light-duty vehicles (cars) to light-duty trucks (minivans, SUV's, and pick-ups) for everyday driving. EPA has implemented a binning protocol where eleven different bins have been created with different numerical standards in each bin. Further complicating matter is that in §86.1807-01, EPA asks OEM's to include both the certification and, if different, the in-use emission standards including bin into the compliance language of the decal text. However, there is an important new provision in this same part: EPA says that in lieu of doing this, a manufacturer can use the standardized test group nomenclature provided by the EPA. Not all manufacturers treat this passage equally. GM and others do not choose to include Federal emission levels into the compliance language text, while other companies such as Ford do provide this information. Any additional information provided beyond the bare minimum is an increased jeopardy of recall action. A further discussion of philosophical differences between the approaches of different OEM's will be covered in section 6.5.

Additional information and changing certification standards require the engineers to stay abreast of all regulatory developments. A failure to do so could be seen as a lack of process maturity and will typically result in a greater rate of errors.

6.4. LEV I vs. LEV II (California)

California first adopted LEV regulations for phase-in beginning in the 1994 model year. However, they too have made significant changes. In 1998, CARB amended the LEV regulations with LEVII changes. These changes are to be passed-in beginning with the 2004 model year, similar to Tier II Federally. The numerical LEV II standards are listed in Appendix A, Page 85. The main changes include:

- Extension of passenger car standards up through 8500# GVWR
- Tightening of fleet average emission requirements
- A significant reduction in NOx numerical standards for low and ultra-low emission categories
- Increased full useful life of all vehicles under 8500# GVWR to 120,000 miles
- Creation of partial Zero Emission Vehicle (ZEV) credits
- Further reduced evaporative emissions

Unlike the Federal Tier II regulations, California regulations do require that the emission level be spelled out in the compliance language text. With all of these changes, emission decal design and release engineers need to be more vigilant in their scrutiny of incoming paperwork. Contrary to perception in other parts of the company, the design and release is not simply the release of a few 'stickers'. Instead, this team needs to be up-to-date with all emission regulations and has been required to serve as a gatekeeper for certification information supplied to them. It is not uncommon for the team to catch errors that might otherwise make it into the field on vehicles or submitted to the regulatory agencies in the Applications for Certification.

One additional note can be made on the subject of the tightening of fleet average emission requirements. This has introduced flux into the strategy and planning for future model years. As fleet averages are required to drop, planning compensates by tightening emission targets for both future and some current model year products due to the limiting banking of credits possible. Without discipline in the process cascading down from high levels, this flux tends to create rework and late changes to the certification process and the emission decals.

6.5. GM vs. Ford Approach

GM has taken a very literal approach to the regulations. If the U.S. EPA, CARB, or other foreign governments clearly ask for something in the regulations, they will give it to them. If it is left to the judgment of the manufacturer or if there are special requests by the agencies, GM tends to include only the essentials, denying all requests for additional information. It appears that Toyota also tends to take this same approach, as can be seen from the Lexus emission decal photo. Perhaps this can be traced to the same group in GM interacting with the agencies, certifying the vehicles, and designing and releasing the emission decals.

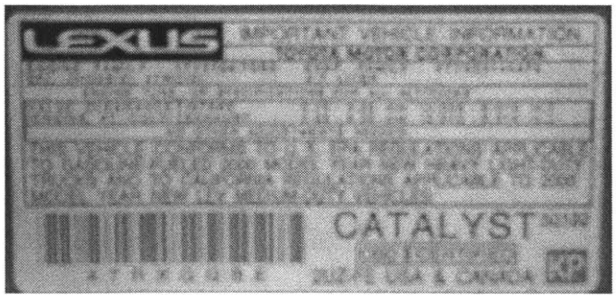


Figure 23. Lexus (Toyota) emission decal example demonstrating the simplified approach followed by GM, Toyota, and others. Note the absence of a Federal emissions level in the compliance language text.

Ford takes a very different approach. Ford tries to be much more accommodating with the regulatory agencies, often complying with requests of the agencies that have not been written into the regulations. For instance, in 1996, EPA asked manufacturers to start including the type of gasoline (two major ones are used in the U.S. Howell EEE (aka Indolene Clear) or California Reformulated Phase II fuel) used in certification on the emission decal. This is clearly not required. Regulations state that "vehicles designed to be capable of operating on fuels other than gasoline or diesel, the statement ``This vehicle is certified to operate on [specify fuel(s)]''"[22] must be included on the decal. The agencies were asking for something above and beyond the regulations. The group within Ford tasked to work with the agencies agreed to the request before Ford OGC overruled and denied the request. However, since that time there has been a turnover of OGC lawyers. Since legal interpretations are often subject to the reading of an individual lawyer, it is unclear how a similar request might be answered in the future.

It should be noted that perhaps some of these special requests are agreed to because, unlike GM, the group within Ford that interacts with the regulatory agencies and has ultimate responsibility for certification is NOT the same group that does the emission decal design and release. Even within the same company it may be easier to agree to additional work when you are not the one responsible for it. These side agreements add complexity to an already difficult job. They also make the 'bookshelving' of these agreements absolutely essential so that a history on how policies were developed can be seen and studied by those new to the process.

This lack of a 'lessons learned' database played a role in the recall campaign in our case study of Chapter 9.

6.6. Organizational Indifference

6.6.1. History of Ford Divisional Development

This is a special look at the Ford system. Unlike GM, Ford has different organizations that interact with the regulatory agencies and that design and release the decals as was alluded to in the previous section. Past relations between the divisions has been one of distrust, but is improving. These divisional 'chimneys' that will be further described tend to complicate the complexity to any process.

Vehicle Environmental Engineering (VEE) at Ford is the division tasked in part to be the interface with the regulatory bodies. VEE did not exist before the early 1970's when a massive recertification effort occurred at Ford. VEE was created as a sort of an internal watchdog to vouch for the integrity of Ford processes and test results. Powertrain Engineering at Ford took a dim view of these watchdogs and perceived VEE as not providing an added value to the final product. They were viewed as a 'necessary evil' that should be worked around whenever possible.

In today's work environment at Ford, VEE is charged with both interacting with the regulatory agencies and formulating the different possible compliance language combinations that can be used in a particular model year. As was mentioned previously, Ford tends to agree to additional requests of the regulatory agencies, when other OEM's do not.

The design and release function at Ford is not part of VEE; rather it is in Core and Advanced Powertrain Engineering (CAPE). Within CAPE, the emission decal engineers retain a closer bond to the group responsible for obtaining, clarifying, and consolidating the information with which Ford certifies their vehicles. This close tie better ensures that the Application for Certification and the decal as designed contain exactly the same information. This group has little say as to the compliance language that is set forth by VEE. If VEE were to suggest something contrary to regulation, the emission decal engineers have the ultimate responsibility to comply with regulations. However, if VEE calls for something to be included above and beyond regulations, CAPE has little choice but to comply. In the past, following an emission decal recall, the Directors of both VEE and CAPE called for all superfluous information to be removed from the decals. But as I have tried to show, there is ambiguity and judgment calls that need to be made, as well as a change in personnel from that time.

6.6.2. Differences – Organizational Process Look

Attempting to illuminate some of the differences between VEE and CAPE further, I looked at the organizations through the three lenses of Organizational Processes[23] – strategic design, cultural, and political.

1. Strategic Design – This lens has the premise that in a well-designed organization each person and each part of the organization can and should be oriented to accomplishing its goals. There is definitely a lack of internal alignment and ineffective linking present between VEE and CAPE. While CAPE has a group specially tasked to emission decal issues, there is no corresponding group within VEE. Within VEE, for most people emission decals are a relatively small part of the job or an annoyance on which little time is spent. A dedicated group within VEE to handle all regulatory issues might help alleviate some of these inconsistent goals.

2. Cultural – When VEE was formed in the early 1970's, they were formed in response to an emergency facing Ford. However, many of those initially delegated to VEE were new hires or cast-offs from other areas. Due to a limited cross-pollination of workers, it took many years for VEE to move past its image as a second-class citizen. Today, there is an interesting dichotomy within VEE. The rank-and-file employees are often left doing routine data processing and meeting facilitation tasks. But those promoted to management are not subject to as many rules as other parts of the company (including CAPE) and enjoy a great deal of relative freedom. For instance, much of the management in VEE has no direct reports, which is almost unheard of in CAPE.

Since many of those VEE employees directly involved in certification efforts are from the lower ranks, there is an authoritarian approach where decision-making power is concentrated at the manager level. By contrast, in CAPE, the emission decal engineers have a wide range of decision-making powers that traditionally have been held at much higher levels in other parts of the company. It is not uncommon for an emission decal engineer to interact directly on an infrequent basis with a vehicle line director or higher.

3. Political – Politically VEE (~200 employees) tends to be tied to higher levels of the company. Certification is absolutely necessary, so VEE is largely left alone internally to accomplish this task. They tend to have the ear of upper management even though they are a much smaller organization and have a higher percentage of employees at higher pay grades. CAPE, on the other hand, is a much bigger organization (~2000 people) that has many diverse roles. The emission decal design group tends to get 'lost' in the larger CAPE picture and objectives. Management has little time to spend on emission decal process improvement efforts until such time as a recall surfaces and fire-fighting mode is entered. There are more people and levels within CAPE, leading to a dilution of power. CAPE must seek approval from VEE on many certification issues, leaving VEE in a gate-keeping position of power where they can help shape the regulatory process.

Overall, the three lenses of organizational processes provide an interesting way to look at the differences between two internal divisions within the same manufacturer. At Ford, VEE and CAPE have very different roles and responsibilities. In the past, the transfer of emission decal design and release responsibilities to VEE has been investigated, but in order to better link the decals to the information sources on which they are derived, it was decided that leaving the responsibility within CAPE was prudent. This is supported by research conducted by Tom Allen of MIT who found that physical proximity actually improved communication within a team[24]. However, to better link Powertrain and VEE, a full-time dedicated heavyweight team with members from both VEE and CAPE (at a minimum), with the team leader being a technical specialist or senior engineer from within CAPE might be a prudent undertaking.

A heavyweight team has a project manager with direct access to and responsibility for the work of all those involved in the project. The core members of the team are dedicated to the project and very often physically co-located, but are not assigned on a permanent basis. These teams need strong, independent leadership, broad skills, and a cross-functional perspective, but may conflict with the entrenched functional organization. They need a clear mission and a qualified heavyweight project manager who has earned the right to the role based on prior experience, developed skills, and status earned over time rather than simply being designated the leader[25]. The benefits of such an arrangement on the accurate release of emission decals and the effective management of certification changes may help to span current organizational boundaries.

Divisional 'chimneys' can add complexity through additional information transfers and narrowing the scope of what any one employee is required to know to perform their specialized task. A systems understanding is not absolutely essential to doing a highly specific task. However, without a systems understanding, more work may be created for those downstream in a process. A heavyweight is an effective way to foster cross-divisional discussions and a more complete systems understanding.

6.7. GRC Indifference

Also present in the emission decal process in an air of indifference or belief that emission decals are not important. For every assembly plant there is a Government Regulations Coordinator (GRC) who has ultimate responsibility to ensure that all vehicles leaving the plant comply with all applicable government regulations. The emission decals are denoted with an inverted delta (∇) signifying an extremely important regulated part that is must be specially addressed in the plants' assembly plans. In fact, perhaps in part to the perceived simplicity of the part, very little attention is routinely given to these parts. Until recently it was not uncommon for *no* checks to be made after installation to ensure that the proper decal was installed on the proper vehicle. In a recent example, one assembly plant did not look at the engineering release system to determine how the usage on four decals differed. Instead, they just assumed that the difference was the same as the year before. This is an example where all the correct information was provided and made it to the correct decals. In turn, the decals were correctly released in the engineering release system and were coded properly by the release writers. However, an assumption was made at the assembly plant, leading to a $50,000 recall campaign. No check of installation part accuracy was formally conducted. This quality of checking will be addressed in the modeling to follow and can be changed to see how this might affect recall costs.

This chapter tried to place the emission decal in the context of a political work environment that is constantly undergoing change from an increase in applicable regulations. To reduce warranty costs, all of those involved in the emission decal design and release process must proactively work together across boundaries and be on the leading edge of understanding new regulations and their potential impact, even before final regulation passage, in order to develop a plan on how to react with minimal disruption and negligible error rate.

PART III – SYSTEM DYNAMICS

Chapter 7. Background and Base Model Development

7.1. System Dynamics Background

Professor Jay Forrester founded System Dynamics at the MIT Sloan School of Management in 1956. System Dynamics is a discipline that analyzes the behavior of systems in a variety of fields such as environmental change, politics, economic behavior, medicine, and engineering[26], often when the results occur with a significant time lag to the policy changes. I will be utilizing System Dynamics to look at the engineering design and release process of automotive emission decals. System Dynamics is a method for studying and managing complex feedback systems. The study of the whole system as a feedback system is necessary to lead to correct conclusions. Incomplete understanding of complex systems can lead to incorrect conclusions.

The general methodology is an iterative process that typically involves[27]:

- Identifying a problem
- Developing a dynamic hypothesis explaining the cause of the problem
- Building a computer simulation model of the system
- Testing the model to be certain that it reproduces the behavior seen in the real world
- Devising and testing alternative policies that help to alleviate the problem
- Implementing the solution

An important point to keep in mind is that the first problem identified could possibly be only a symptom of a still greater problem yet to be uncovered.

7.2. Development of Base System Dynamics Model

7.2.1 Main Stocks and Flows

The base model was created in Vensim software[28] and was developed for this thesis with a series of stocks and flows and six rework loops iterating back to earlier steps in the process of getting an emission decal designed and released correctly. The general structure of the rework flows are similar to those presented by Ford and Sterman[29]. The base System Dynamics model is shown in Appendix C.

The main stocks, or reservoirs, are:

- Decals to do
- Completed but not checked
- Approved
- Released but not checked
- Released
- Coded but not checked
- Coded
- Ordered
- Received
- Installed but not checked
- Installed

- To be externally approved
- Externally approved decals

The decals flow from one stock to another, which are constrained by available resources, average duration, and the stock available to flow to the next stock. A sample of the first few stocks and flows is included in the following figure, with the complete main stock and flow structure attached in Appendix D.

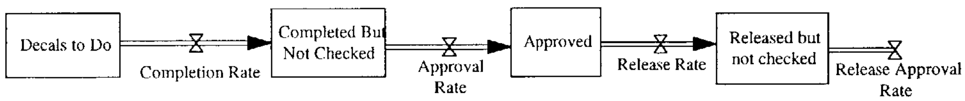


Figure 24. Truncated main stock and flow structure. The full main stock and flow structure is Appendix D.

7.2.2. Rework Flows

There are five rework flows back from the ideal release process into the stock of tasks to be changed.

- Internal Error Discovery Rate
- Release Error Discovery Rate
- Coding Error Discovery Rate
- Installation Error Discovery Rate
- Late Decal Error Discovery Rate

The first rework flow, an internal error discovery rate by the decal engineers, is designed to catch immediate errors that may have occurred in transcribing information by the decal design and release engineers or by the supplier. These changes can be implemented more quickly than a task requiring further coordination. A glimpse of this one rework flow is included in the following figure.

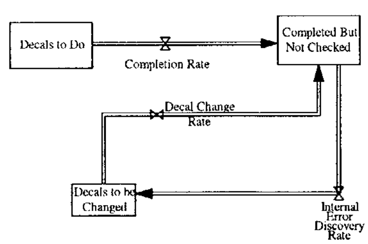


Figure 25. First rework flow of internal error discovery.

The remaining four rework flows require coordination of design and release tasks with other activities, thus requiring longer average durations. Appendix E contains a simplified diagram of all five rework flows.

7.2.3. Error Co-Flow

There is also a co-flow to the original core series of stocks and flows. The stocks in this co-flow are:

- Completed with errors
- Decals approved with errors
- Released with errors but not checked
- Released with errors
- Coded with errors but not checked
- Coded with errors
- Ordered with errors
- Received with errors
- Installed with errors but not checked
- Installed with errors
- To be ext (externally) approved with errors
- Ext (Externally) approved with errors

This co-flow is designed to capture the decal errors that are propagated through the process. At each check point corresponding to the discovery rates described above, a percentage of the as of yet undiscovered errors are indeed identified and are removed from the co-flow of undiscovered errors. A sample of the first few stocks and flows in this error co-flow is included in the following figure, with the complete error co-flow structure attached in Appendix F.

Included in this example is a rate called 'New errors release rate'. This flow, and two others like it in the full model, allow for new errors to be introduced into the design and release process once a decal is progressing through the complete design, release, coding, and installation process. Not all errors are design errors, so this structure allows for the introduction of new errors in later steps.

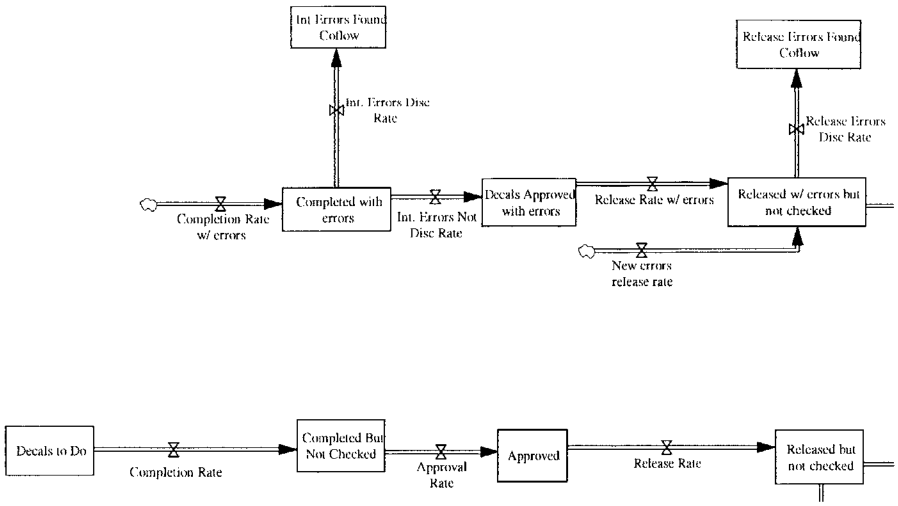


Figure 26. Sample of the error co-flow structure in parallel with main stock and flow structure. Please note that in the full models the structures are linked together.

7.2.4. Recall and Cost Structure

Separate from the main flow, co-flow, and rework flows in the core of the model, there are also flows into a stock of recalls. Flows into the stock of recalls are release, coding, and installation errors not immediately corrected, a percentage of the late errors eventually found depending upon the time required to discover the errors, and the odds of an undiscovered error eventually coming to light. The stock of recalls is converted into 'Real Cost' by multiplying by average usage and average fine per vehicle. Likewise, a maximum possible cost parameter ('Max Cost') is calculated using the potential for fines as outlined by regulation, which was covered in a preceding section. A look at this recall and cost structure is included in Appendix G.

7.2.5. Other Important Vensim Structural Components

Several other important features of the base model are well worth mentioning. First, as was mentioned previously, the five tasks accomplished by the emission decal design and release activity are jointly constrained by the time available to the design and release engineers. The five tasks are:

- Decal Completion
- Decal Change
- Decal Coordination
- Decal Release
- Decal Check

The personnel requirements required for each of these five tasks are equally weighted since each is a vital task that must be performed. The fractional constraint on resources is therefore the same for all five tasks. A greatly simplified view is attached as the following figure to facilitate readability. Total required design and release personnel for the five tasks at hand drive a fractional constraint that is multiplied by the feasible rate for each task, leaving perhaps a slower flow than anticipated through each gate. This is very important in this model because of the growing requirements of the decal design and release engineers from the growing regulatory, informational, and process complexity. Each tends to drive the 'Effective Staffing' parameter lower, thus slowing the completion of these five tasks.

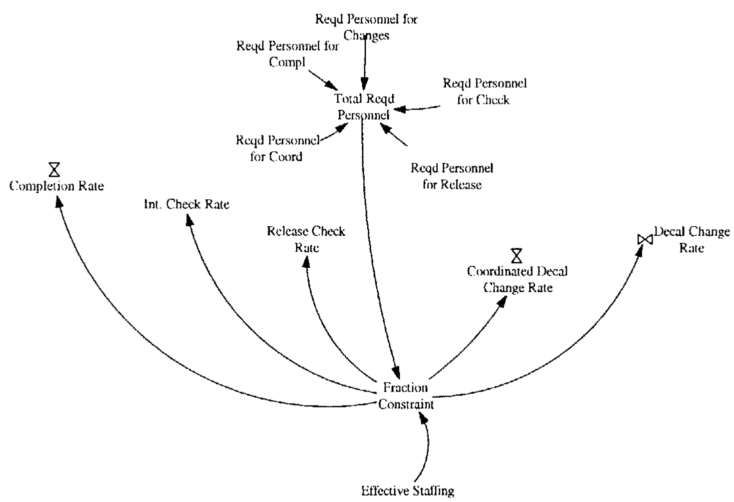


Figure 27. Simplified view of the fractional constraint structure on the decal design and release engineers' time.

Second, actual staffing is reduced to an effective staffing level by the number of interruptions to the core task (phone calls, electronic mail, meetings, etc.).

Third, work quality in the model is based on the work experience of the direct staff and on stress level - that is in turn affected by the support of management and the number of interruptions that the design team encounters on a daily basis.

7.3. Base Case Results

The base model has been calibrated to provide approximately the same average annual results as that of a typical large automotive OEM. A graphical summary of key parameters in the base model is included as an introduction to the changes that will be studied in the three case studies to follow. This base case contains no late changes and uses the current experience levels of the current decal design and release engineers. The timeline for each Vensim graph is 365 days and is intended to simulate one model year.

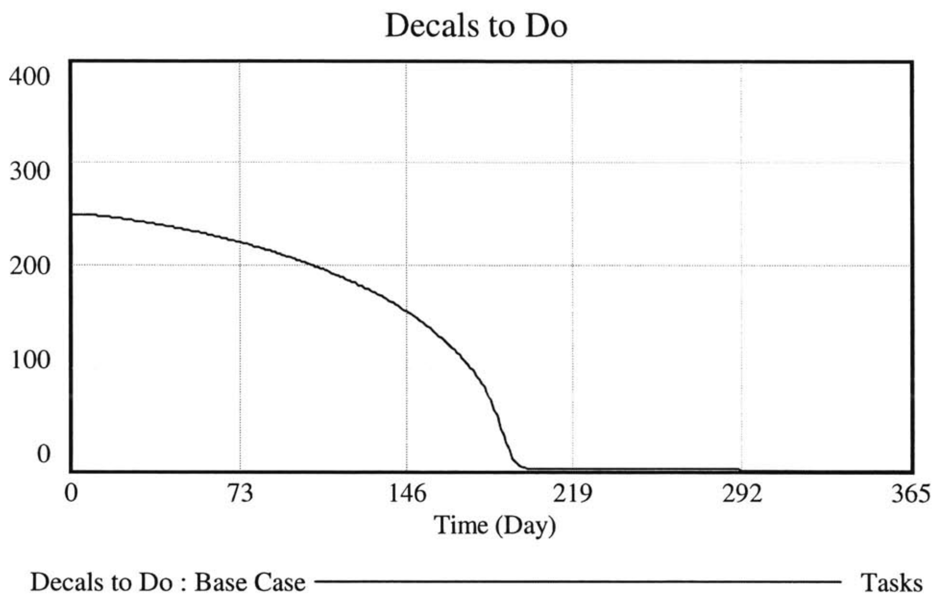


Figure 28. Base case of 'Decals to Do'. This is the initial stock of 250 decals to do per model year. If all information were available, this initial completion takes approximately 6 months.

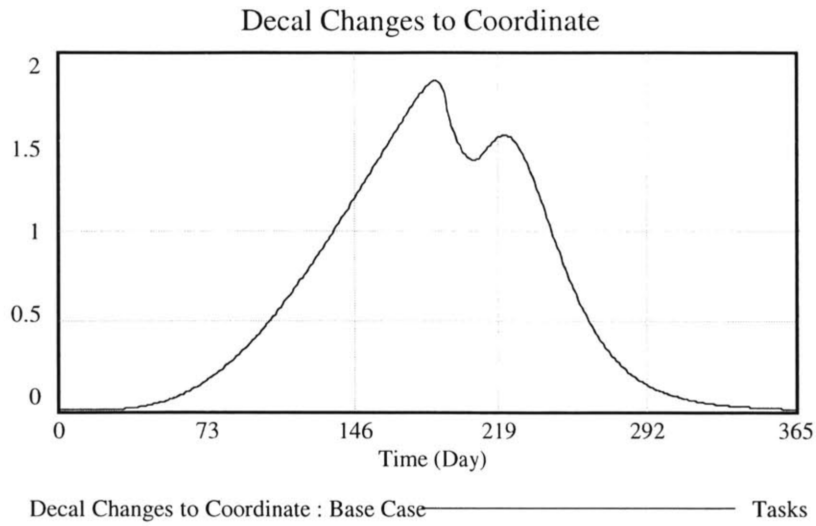


Figure 29. These are the Base Case decal changes that require coordination with other activities. Notice the slight backlog in the middle of the model year that is resolved by model year's end.

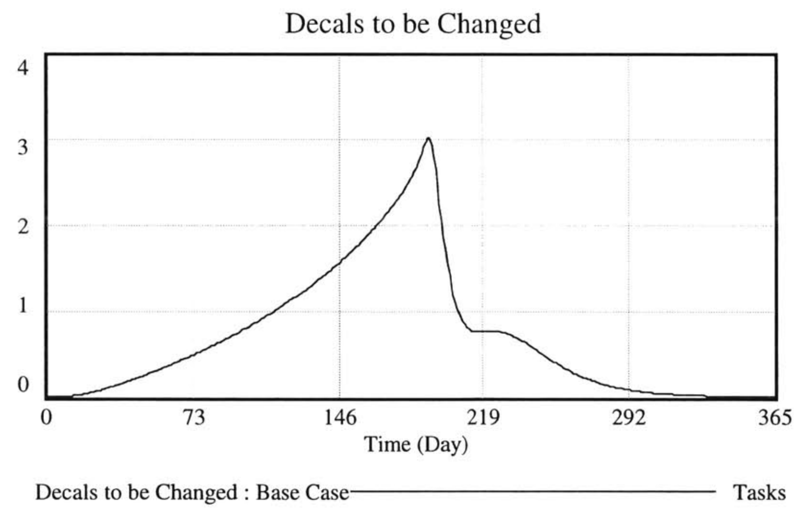


Figure 30. This is the Base Case level of decals that need to be changed. These are errors that are either caught immediately, or changes still pending after the coordination activity is complete.

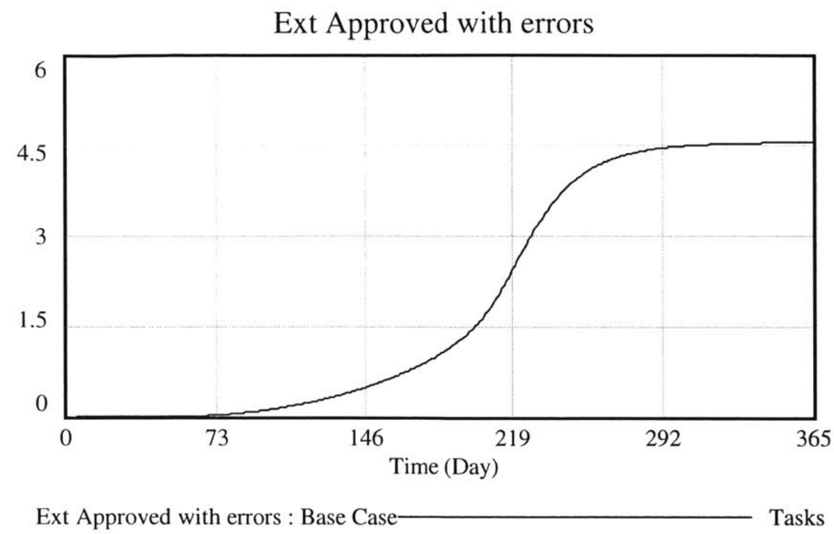


Figure 31. This the Base Case level of decal errors that make it into the field undetected each model year after every checking mechanism has been exhausted.

The 'Ext Approved with errors' value does typically agree with the number of emission decal campaigns required. For the decals to be approved with errors at the end of the entire process means that every checking mechanism has been exhausted and that these errors have made it past all five re-work cycles. The number of emission decal campaigns contains a portion of these as yet undetected errors that are eventually discovered after a significant time lag. However, the number of emission decal campaigns also includes a portion of the errors caught in the later re-work cycles. It is possible for a systematic error to be made (one such example will be discussed in Chapter 10), where a number of vehicles are incorrectly labeled before the error is actually discovered through one of the checking mechanisms.

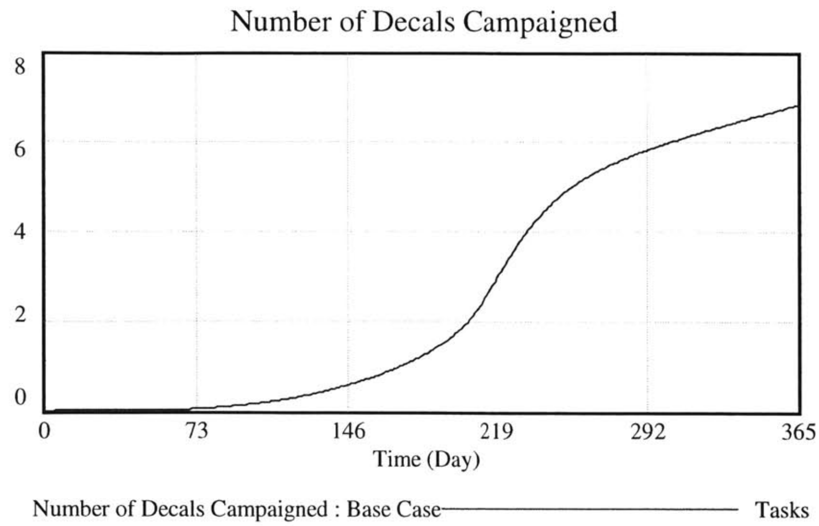


Figure 32. This is the Base Case level of recall campaigns each model year due to an error in the emission decal process. Although this number may seem small, the potential for monetary fines and decreased customer satisfaction is real.

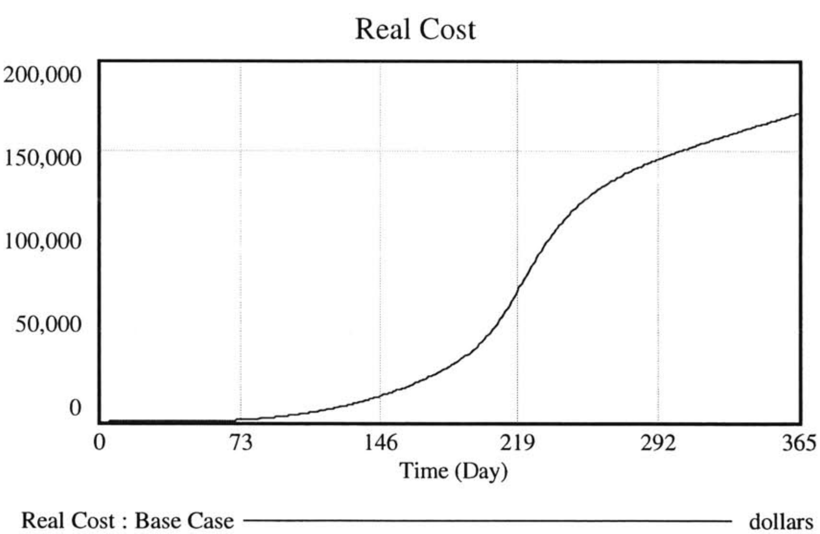


Figure 33. This is the Base Case real monetary cost of emission decal recalls. This agrees with the historical data available, but may only be a fraction of the perceived cost to the company via customer dissatisfaction.

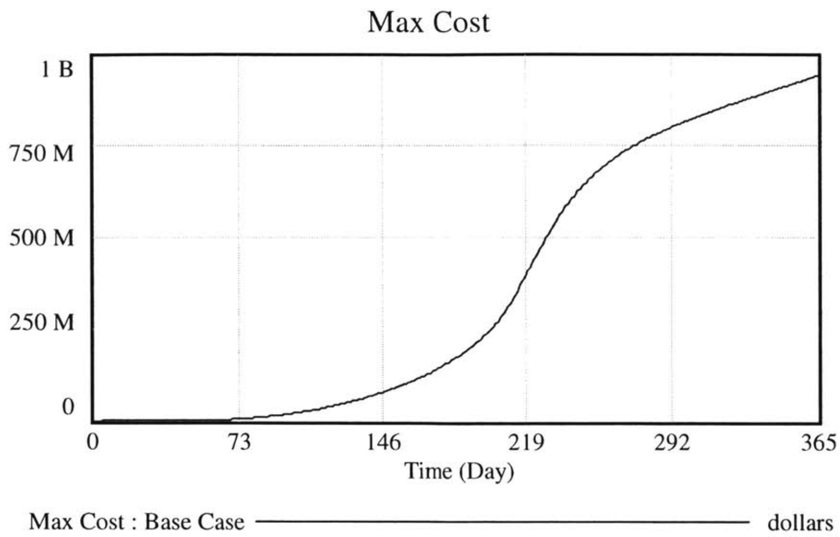


Figure 34. This is the Base Case maximum possible cost of fines based upon the number of recalled emission decals. The chance for this level of fine is remote, but is conceivable and must be considered when changes are considered.

As can be seen from Appendix C, the number of parameters in the model is numerous. Many different parameters can be isolated for further study. For the purposes of this thesis, the author used the previous seven graphs as a baseline to which the case studies will serve as modifications and results compared.

Chapter 8. Case Study 1: Coordinated Change

8.1. Coordinated Change Scenario

The first case to which the System Dynamics modeling tools will be applied is a common coordinated change. An excellent example of a coordinated change is when a manufacturer decides that it must meet more stringent emission standards to meet emission phase-in plans. To do so, the manufacturer must often alter the precious metal (platinum, palladium, and rhodium) in the catalyst to meet emission objectives. The catalyst is one of the more expensive parts (or system, depending upon your view – "one person's system is another's component"[30]) on a vehicle. Current prices as of September 2003[31] are $704/oz of platinum, $218/oz of palladium, and $450/oz of rhodium. This provides a real incentive for manufacturers to limit or even reduce the amount of precious metal in each catalyst, but stricter emission standards can result in more precious metals being used. Once a new catalyst is tested and proven out in internal testing to meet emission standards and durability requirements, a new test group is certified with the appropriate regulatory agencies. Once certified, a manufacturer will decide on a date to introduce this change, but it is absolutely imperative that the emission decal be changed at the same time as the catalyst. This is where the name 'coordinated change' is derived from.

As was discussed earlier in section 5.4, forward model year planning can necessitate the tightening of emission standards in the current model year. For instance, referring to the Federal Tier II emission standards in Appendix A, a late change might require a program to demonstrate compliance with Tier II Bin 8 (T2B8) emissions standards rather than Tier II Bin 9 (T2B9). For NOx emissions, this is a tightening of the standard from 0.300 g/mi to 0.200 g/mi at 100,000 miles. In order to comply, it may be required for the program to use a catalyst more heavily loaded with precious metals. However, note in Appendix A that for a passenger car or LDT1, the NMOG 100K standard actually increases from 0.090 g/mi to 0.125 g/mi going from Federal T2B9 to T2B8. In this case, it is conceivable that the new catalyst required to meet the T2B8 NOx standard can no longer meet the T2B9 NMOG standard. In this instance, the emission decal must change at exactly the same time as the catalyst (and most likely the processor). This is the essence of a coordinated change. Several changes must happen in unison to comply with regulations.

8.2. Coordinated Change Difficulties

Unfortunately, often a coordinated change does not come off as planned. New parts are released into the electronic engineering system database via 'Concerns' that in turn feed

'Notices' when approved. Because there is a constant turnover of personnel and each program tends to act as an island, it is not uncommon for programs to be unaware that catalyst or processor changes often drive decal changes. Concerns, manually forwarded, describing these changes do not always reach all affected parties, including the decal design and release engineers. To further complicate matters, program management activities are tasked to close Concerns and Notices as soon as possible. If the decal designers are aware of an upcoming catalyst and/or processor change, they often release their own separate concern and try to tie their decal change to the catalyst/processor change after-the-fact. Because the decal design engineers may not yet have all the information they need to proceed, this separate Concern removes the longer lead item (decal) from the other, quicker Concern (catalyst/processor) and can remain hidden from the individual program teams until all information is received. This eliminates a number of interruptions and substantially improves work productivity by raising effective staffing in the model.

However, this separation of Concerns can lead to the parts not being implemented in unison as required, leading to rework and a possible recall situation. Upper management with Product Development and Vehicle Operations (assembly) would need to provide clear direction to all program management activities and assembly operations as to a policy change for coordinated changes whereby Concerns and Notices can remain open for a substantial length of time without prompting numerous meetings and status reports. Without this high level buy-in, it would not be feasible for most decal changes to 'piggy-back' on the existing Concern. The prolonged time for the release to stay open would instead hamper productivity to the point where effective staffing was not sufficient to complete all required tasks. As the following graph demonstrates, with enough interruptions, productive work is hindered to the point where an average of one phone call, meeting, or status report every 15 minutes (96 interruptions = 3 people x 8 hours x 4 interruptions/pp) can result in work not being completed as required.

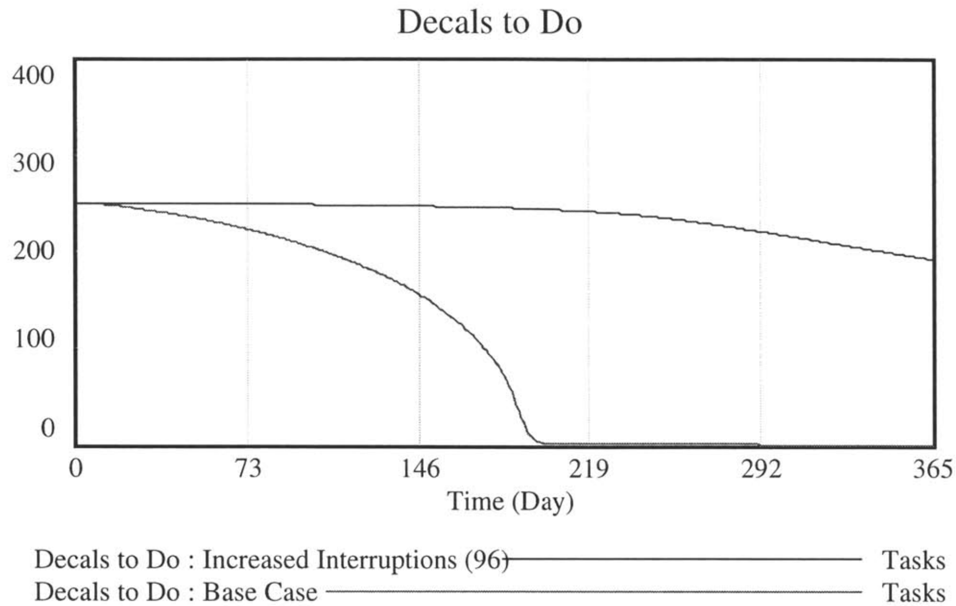


Figure 35. Increased interruptions or additional responsibilities can ultimately result in all necessary work not being completed as required.

8.3. Information Transfer Required in Coordinated Change

The larger issue with any coordinated change, whether or not it involves emission decals, is the effective transfer of information and growing information gaps between functional entities. Increasingly, subject matter experts are developing who are very good in their area of expertise and who make very few errors. However, these subject matter experts often do not take a systems view nor do they understand who and what are affected by changes that they make. Current product development efforts are designed at developing additional technical expertise by slowing internal churn within a company. A deleterious effect of this policy could be the creation of additional experts who cannot span the information gaps in the current systems. Subject matter expertise and an ability to translate knowledge to other functional groups will need to be watched closely from a policy perspective. In the vensim model, time on the job generally does improve work quality; however, the curve is 's'- shaped with a plateau of diminishing returns once the learning curve flattens.

In an October 2003 meeting at one OEM, several dozen people converged in a meeting to discuss the inherent difficulties in coordinated changes, with most not exhibiting a firm grasp on the system as a whole. Rather subject matter experts convened for a lengthy meeting where most of the time was spent trying to educate one another on the aspects of their individual tasks before policy changes could be discussed or possible effects investigated. Often those with the most to share are also those who have the most to learn. Internal politics, personalities, and relative position within the company also play a role in the effectiveness of information transfer.

8.4. Vensim Modeling Changes for Coordinated Change

Returning to the vensim model, the coordinated change meeting mentioned above was scheduled to discuss a late change to multiple emission decals that required coordination. The decals were designed and released into the engineering system properly, but were not coded and implemented correctly so that they would be used in unison with the new processors. Only a late check, after the decals were installed on vehicles and in high volume production use at multiple assembly plants, led to the error being discovered. This late error discovery led to a recall, but contained what could have been a significantly larger problem had the error gone longer before discovery. The base model treated the release and coding quality of coordinated parts exogenously (99% and 98% respectively – tuned to available data), the revised model for coordinated changes shows a 'Coordinated Parts Agreement' input into the error rates of the coding and installation of emission decals.

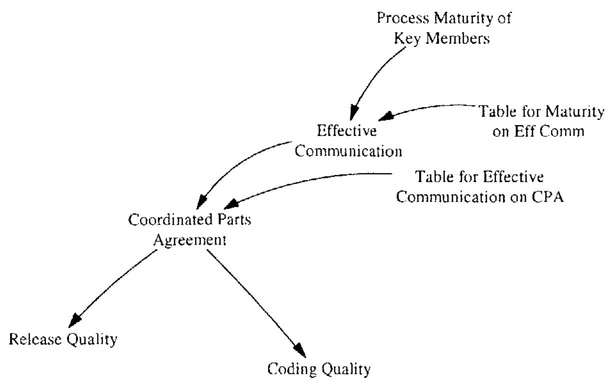


Figure 36. First change for the first case study. Process maturity affects effective communication of the key players, which in turn affects both the release and coding quality.

Likewise, the revised model contains a stock of desired late changes (presumably most for cost reduction actions), and a flow of the desired late changes into the stock of decals changes to be coordinated. As intuition suggests, the increased number of changes requiring coordination does ultimately impact the number of recalls and additional cost to the company. Two different levels of additional late job scope are tested to gain insight.

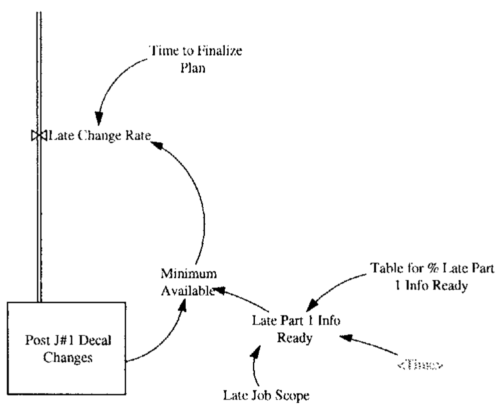
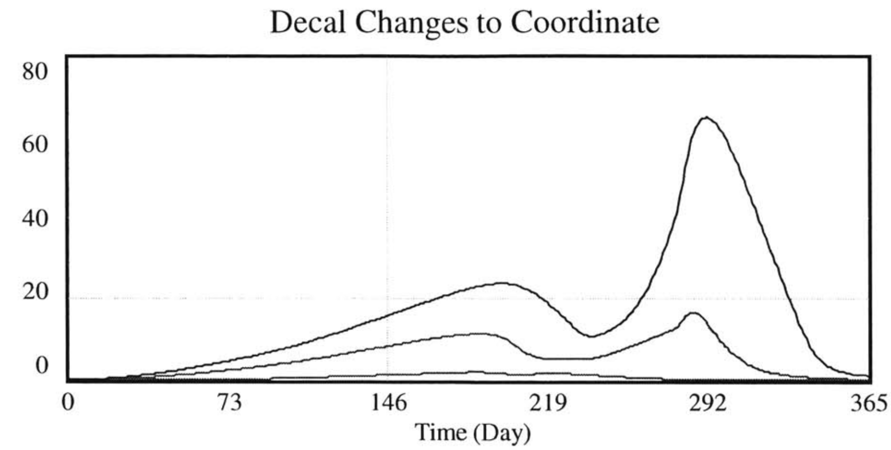
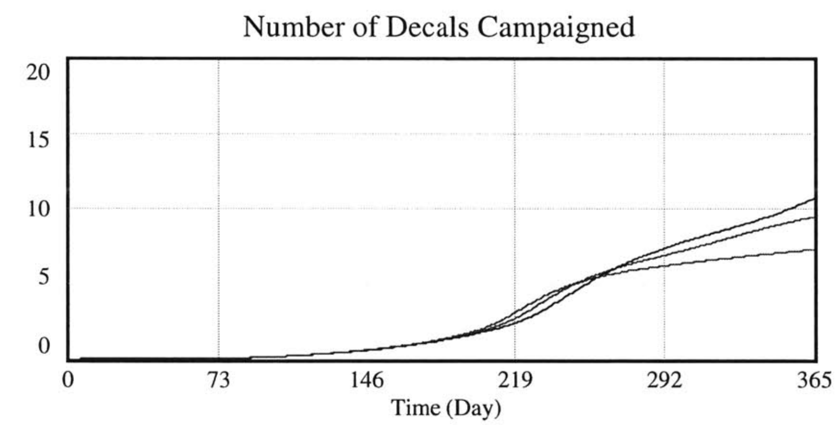


Figure 37. Second change for the coordinated change case study. Late Job Scope can be varied to show the impact of late changes on changes to be coordinated, number of recalls, and monetary cost of these recalls to the OEM.



Decal Changes to Coordinate : Added Late Job Scope (250) Tasks
Decal Changes to Coordinate : Added Late Job Scope (125) Tasks
Decal Changes to Coordinate : Base Case Tasks

Figure 38. Comparison of decal changes to coordinate between the Base Case and with two different levels of Late Job Scope. Notice the shift later and with a higher peak as more late changes are added.



Number of Decals Campaigned : Added Late Job Scope (250) Tasks
Number of Decals Campaigned : Added Late Job Scope (125) Tasks
Number of Decals Campaigned : Base Case Tasks

Figure 39. Added Late Job Scope increases the number of emission decal campaigns. More opportunities for errors are created as well as tasks competing for time.

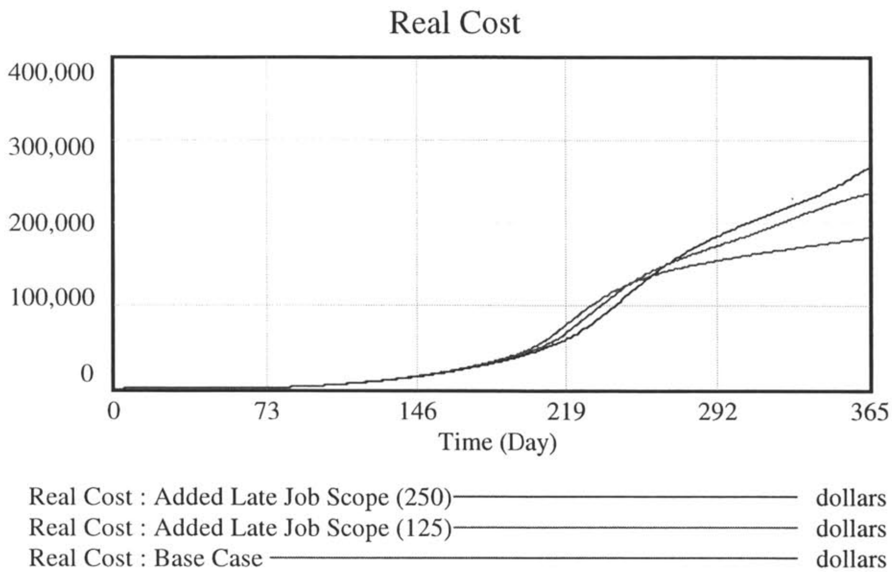


Figure 40. Monetary cost to the OEM associated with emission decal recalls is increased almost 50% from the Base Case to the added 250 task Late Job Scope run.

In the course of interviews to support this paper, it was clear that engineers and management alike both realized that late changes increased stress, taxed the system, and created more opportunities for errors. However, there was not a clear understanding demonstrated on how much these late changes would cost via recall campaigns. The prevailing mindset disassociated the two and could not give an actual dollar figure estimate on the actual campaign costs arising from these late changes. It is the author's experience that when the root causes of emission decal recall campaigns are discussed, late changes in the process are rarely seen as a contributing cause – everything is expected to proceed flawlessly in a complex system. These Vensim modeling results further support the hypothesis that the lack of a systems mindset can lead to more recalls by key personnel not recognizing the cause and effect.

Chapter 9. Case Study 2: Continental Fan Warning Label

9.1. Pointer Label Scenario

In part because there is no standard emission decal size and location, significant effort was expended developing a template for the 1998 Lincoln Continental. It is typical for program teams to push for as small a label as possible and to push the envelope on how to 'hide' a decal and still have it 'readily visible'. The Continental team changed proposed location several times in the early development stages. Eventually, legal counsel agreed to a location that would place the emission decal directly on the radiator support, but under a sight shield attached with Velcro strips (see Figure below).

Figure 41. Emission decal located on the steel radiator support on the Continental, obscured by a sight shield attached by Velcro.

However, legal counsel had a provision in order to meet the intent of the 'readily visible' provision: there must be another 'pointer' label on the sight shield indicating that emission information could be found beneath the sight shield. This could be accomplished by attaching these words to a fan-warning label that already was to be positioned on the sight shield. As the 1998 model year began, the same emission decal design and release engineers released this fan-warning label, so this additional passage could be added with minimal cost and effort.

9.2. Pointer Label Difficulties

As time moved on, the design and release responsibility for this fan warning label was transferred from the emissions group to a powertrain core labels groups, specifically established to help alleviate past label difficulties. Additionally, the Ford 2000 corporate policy tried to globalize Ford Motor Company products, leading to a concerted effort to remove as much text as possible from labels and replace them with pictures whenever feasible by regulation so that the same label could be used in all markets. The core group proceeded to redesign the fan-warning label without text so that it could be used in all markets. With this iteration, the language required by legal counsel to look under the sight shield for emission information was lost. Eventually the problem was discovered, but approximately 500 vehicles were built with the emission decal under the sight shield and no label on the shield itself directing someone to look below for the emission information. It was eventually decided by the Office of General Counsel to campaign these 500 vehicles at a cost of approximately $14 apiece.

9.3. Information Transfer Required for Pointer Label Usage

As was mentioned is the discussion of technical versus process maturity in the preceding section, in this instance all technical work was done absolutely correctly. All decals were designed, released, coded, and installed properly. However, there was a communication breakdown between functional groups. OGC did not publish and bookshelf their rationale for the additional language. The emission decal design and release engineers did not publish and bookshelf the rationale behind all service labels that got transferred to the core labels group. The new core group did not seek out the engineer who released the previous version to learn why certain design parameters were originally selected. It should be clearly stated that none of these breakdowns were malicious. In this case the functional activities did not sit in the same building and had little opportunity to interact except when a problem developed. Nor did everyone have a firm grasp on whom to contact with his or her information. This is an example of technical experts not exhibiting systems thinking. Additional technical training would not be expected to alleviate this type of problem. Rather this type of issue points to the need for technical experts working together to develop a systems mindset. With enough interaction, cross pollination of experts from one function to another, and formal systems training and tools, communication errors can be significantly reduced.

Previously, the case for a heavyweight team was made to support information exchanges between groups and the crossing of these information gaps. This case points to the need for more than technical excellence and the heavyweight team is one of the best examples on how to accomplish this goal. In a classic System Dynamics causal loop, the successes of such a heavyweight team could bring more attention to the process, resulting in higher quality inputs, less burnout, and higher quality outputs.

9.4. Vensim Modeling Changes for Pointer Label Usage

Very similar to the preceding case, the revised model for this case contains a stock of desired late changes that is in part brought about by miscommunication between functional activities. The desired late changes flow into the stock of decals changes to be coordinated.

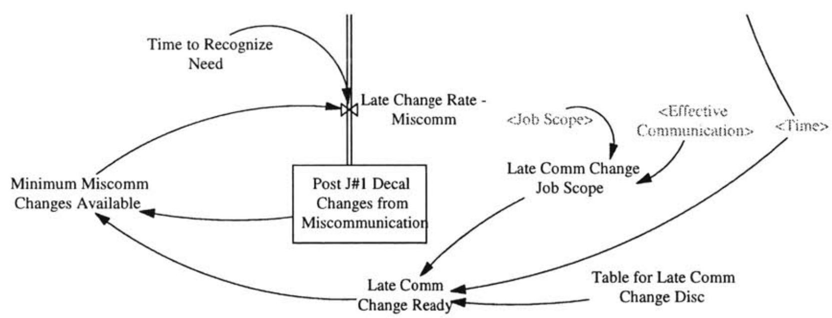


Figure 42. Additional Vensim structure for Case Study #2 showing an additional stock of late changes required due to a late communication change job scope that is fed by poor effective communication from Figure 36.

The increased number of changes requiring coordination does impact the number of recalls and does result in additional cost to the company. Moreover, miscommunications lead directly into recalls in a percentage of cases even when all traditional tasks are done correctly, such as in the aforementioned Continental case study. In the vensim model, effective communication is a function of the process maturity of the key members of the emission decal design and release process (Figure 36). It is clear from the following graphs that process maturity and effective communication do play a role in the recall campaign costs. These figures also demonstrate that as the average process maturity drops, there is a point where the system begins to break down and costs increase sharply.

For the base case, process maturity of the current key members of the emission decal design and release process are rated as 80% process mature (0.8) on a scale of 0-1, with a value of 1 corresponding to the ideal situation where all key members have a firm understanding of how their activity impacts steps later in the design and release process. This evaluation developed in the interview portion of data gathering when key members were interviewed for this thesis. Two additional levels of 30% and 55% process maturity were selected for evaluation to demonstrate how severely additional events to coordinate, recall campaigns, and ultimately anticipated monetary costs to the OEM's are affected by this often overlooked factor. Please note that all three runs in the following three graphs utilize a reasonable late job scope of 125 changes, based upon data available.

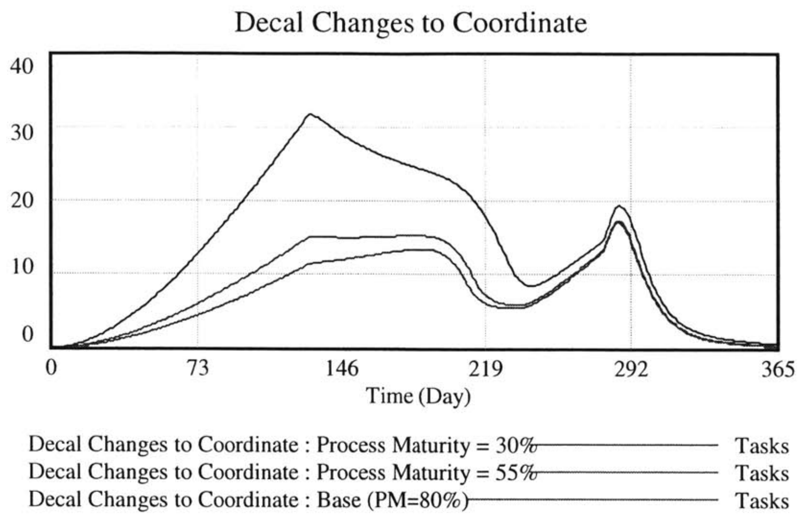


Figure 43. This is a graph of Decals Changes to Coordinate by adjusting the process maturity level of key players in the emission decal design and release process. The base process maturity level was rated at 80%. Lowering this value can significantly increase the number of changes that must be coordinated.

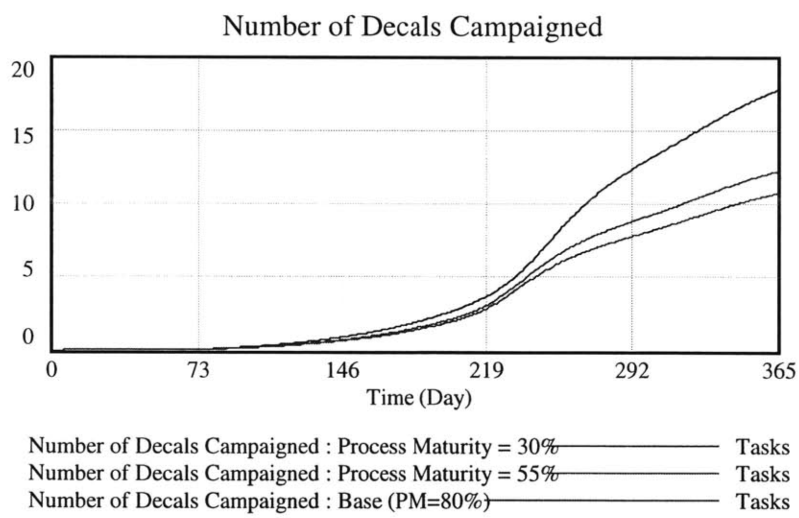


Figure 44. This is a graph of the Number of Decals Campaigned by adjusting the process maturity level of the key players in the emission decal design and release process. Please note the large jump in the number of campaigns when process maturity dips.

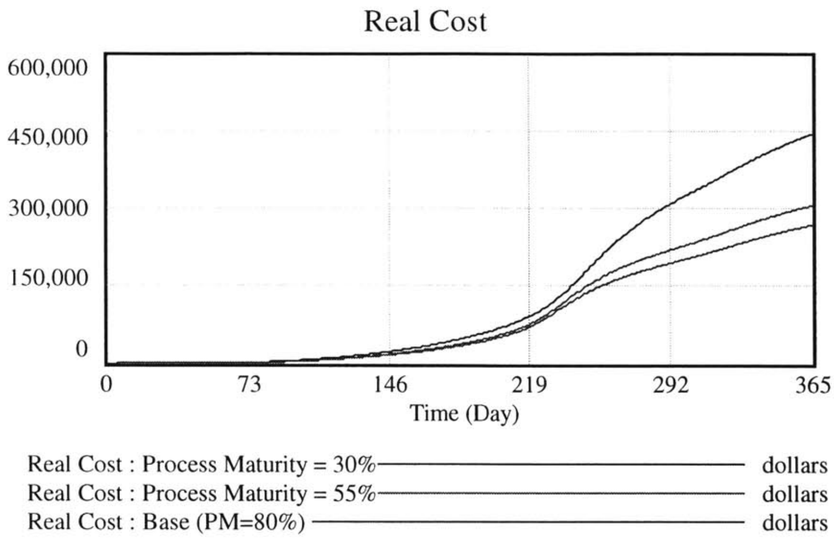


Figure 45. This graph looks at the real monetary cost jump that coincides with the lowering of process maturity of key members in the emission decal design and release process.

Process maturity is important to investigate using System Dynamics because it's impact is not often understood by those people who can best affect change in the process. The impacts are often obscured by a myriad of other changes that can confound the impact of any policy changes or introduce a significantly time delay before impacts are seen. It is the hope of the author that by highlighting these impacts, changes to personnel development can be implemented. The importance of different employees getting a well-rounded understanding of the entire process by either rotating between key functions or involvement in a heavyweight team could speed the maturation process.

Chapter 10. Case Study 3: Missing Engine Label

10.1. Engine Label Scenario

As was discussed earlier in this thesis, Federally certified engines going into vehicles greater than 8500 lbs. GVWR and California certified engines going into vehicles greater than 14000 lbs. GVWR require an emission decal to be installed on the engine itself. Among major OEM's, Ford alone chooses to install a courtesy copy on the vehicle chassis for readability purposes. This is not required by regulation. Design and release engineers at Ford provide usage and installation directions in the engineering release system. Engine release codes the usage into the release system that feeds purchasing of the decals from the supplier. Assembly operations are supposed to take the installation instructions from the release system as well as from installation drawings that are provided by the design and release engineers through the engine illustration activity.

In the 1999 model year, Ford made a process change. Instead of having the ***engine*** assembly plants install a decal on the engine (perhaps different decals (Federal and California) on identical engines), and then have the ***vehicle*** assembly plant hopefully install the same decal, it was decided to have the vehicle assembly plants install both decals. Direction was provided to this effect in the release system, the number of decals to be used per vehicle was set at two, and the installation drawings provided to the plant clearly showed both the decals to be installed on the engine and the vehicle chassis.

10.2. Engine Label Difficulties

However, the truck plant in Kentucky did not implement these changes. The courtesy copy, not required by regulation but in a readily visible position, was installed. The mandated decal on the engine, often not readily visible, was not installed. Although the intent of the regulation was met, the letter of the law was not met. The decision was made internally to recall the ~130,000 vehicles at a cost of approximately $4 per vehicle.

A formal internal investigation pinpointed the root causes as the late release of decals preventing normal check installation runs (disagreement over timing required – Section 5.5), a less than perfect inspection process (GRC indifference – Section 6.7), and miscommunication regarding the process change (referred to throughout this paper).

First, the emission decals cannot be released according to corporate timing for other parts since certification efforts dictate much of decal timing. However, dummy decals could potentially be used. Previously, the dummy decal was a one-size-fits-all decal that was not typically the right size for an individual vehicle line. Also, the complexity could not be accurately described since the complexity (i.e. the number of different decals used on one vehicle line) is dictated in part by how the product line is certified. Since the plant is attempting to verify installation and full build coverage, the dummy decal would not help meet either need. Furthermore, if a vehicle mistakenly made it out of the assembly plant with only the dummy decal, it would be recallable. The dummy decals tend to create more problems than they solve. In short, the emission decal needs special handling by the assembly plants and cannot be considered merely just another part on the Bill of Materials. Late certification efforts have not always been recognized for the magnitude of the downstream effects they create.

Second, the current installation inspection process is prone to error. 6-sigma efforts have focused on this area since it was an area desperately in need of improvement and automation. Two ideas of consideration are bar code readers for 100% installation checks or imbedded Bluetooth chips for drive through checking.

Third, miscommunication did play a role in this recall. However, it is necessary to dig deeper than the root cause investigation. The design and release engineers did everything correctly in the design and in the release direction, while engine release also coded it properly. However, the installation was sub-optimal. The process change was communicated through every formal means available to the design and release engineers so it is difficult to say that it was not communicated properly. But digging deeper, we see that informal communication methods are necessary to fill in the gaps of the formal process. Opportunities for this informal communication include phone calls, e-mails, faxes, etc. It is not preferred to rely on informal communication methods for the proper functioning of any process, but in the absence of a fully integrated automated system, informal communication is often necessary to improve the quality of the end product. A systems understanding of how all the pieces of the process fit together is essential to foster effective communications.

10.3. Vensim Modeling Changes for Engine Label Case Study

In the original Vensim model, installation quality was exogenous and was tuned to available data. In the revised model, there are multiple factors that equally affect this quality - including inter-functional communication level, experience level of GRC, experience level of the design and release engineers, and systems understanding of the design and release engineers.

Figure 46. Multiple factors included that affect the installation quality of the emission decals.

In sum, the greater any of these factors, the better the installation quality, and the lower the number of recalls and cost to the company. For the three graphs to follow, the systems understanding of the emission decal design and release engineers is altered to look at the impact of how a reduced systems understanding can affect the numbers of errors that make it to the field, the number of recall campaigns, and the monetary cost to the OEM's. Any of the six inputs to 'Effectiveness Input to Install' in Figure 46 could have been modified since they were judged to have equal impact, but the 'D&R System Understanding' was chosen because it ties nicely to the process maturity discussed in Chapter 9. The baseline of 75% systems understanding was rated during the interview process and will serve as a baseline for the two new levels of 25% and 50% to be investigated. Again, please note that a late job scope of 125 is used throughout.

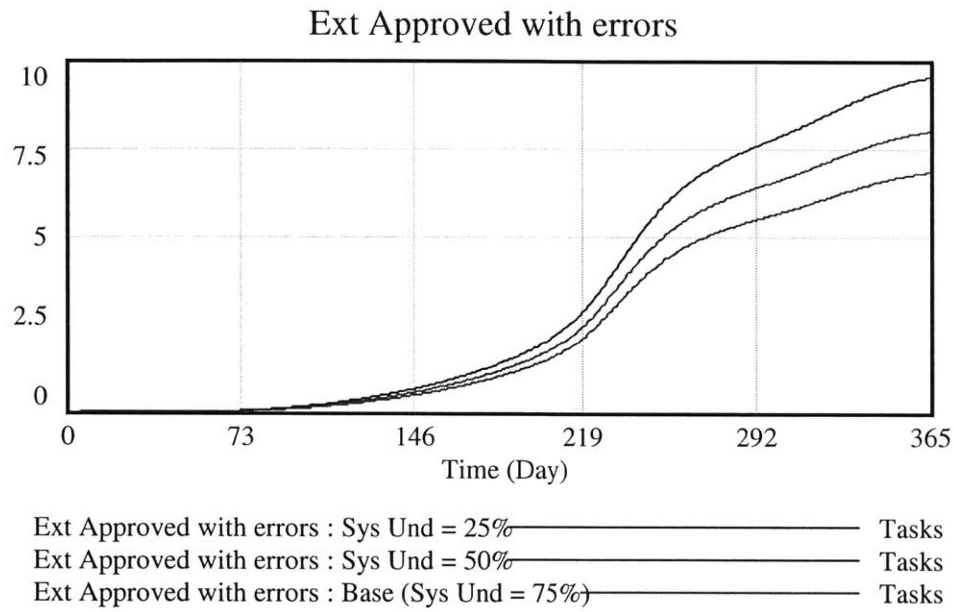


Figure 47. This is a graph of increased errors reaching vehicles in the field due to a decrease in installation quality from a decrease in systems understanding of the emission decal design and release engineers. One possible scenario is that installation drawings are not completed on time.

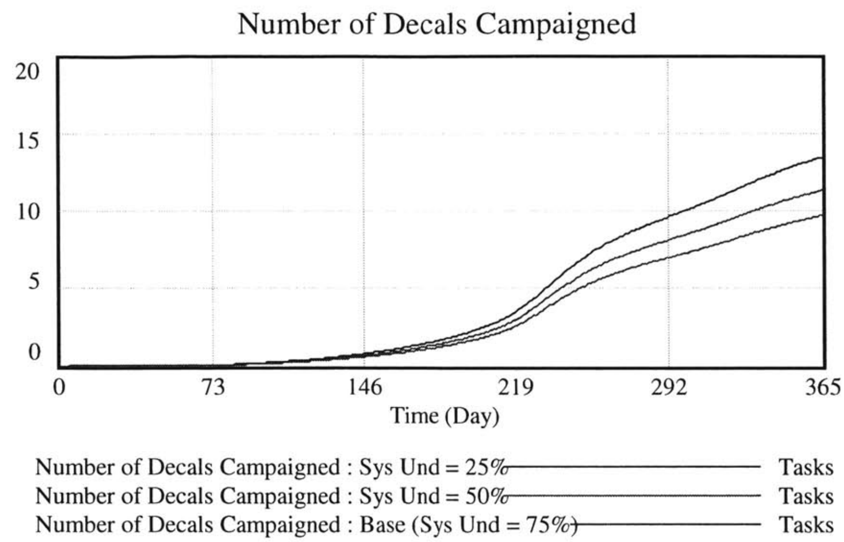


Figure 48. This is a graph of decreased systems understanding of the emission decal design and release engineers leading to decreased installation quality and an increase of recall campaigns.

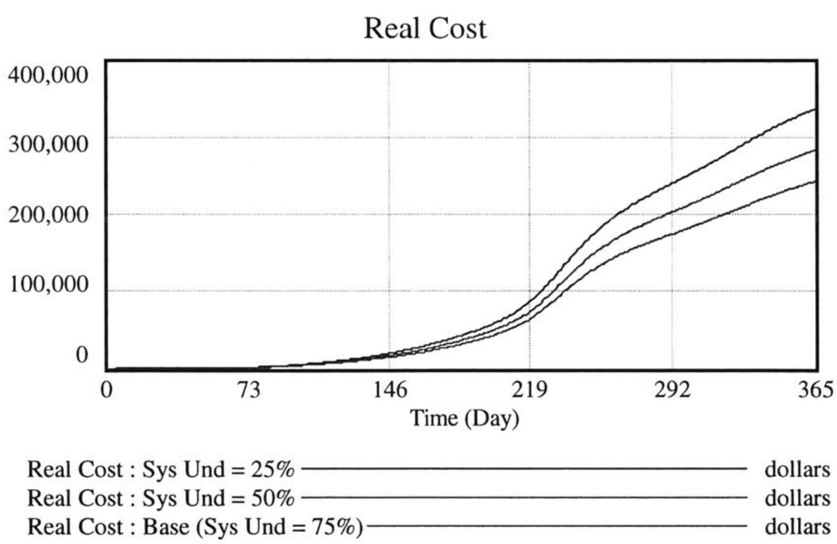


Figure 49. This is a graph of decreased systems understanding of the emission decal design and release engineers leading to decreased installation quality and an increase in recall monetary costs to the OEM's.

System Dynamics is an important tool for understanding these complex relationships because of the numerous factors that can affect timing or accuracy. A lack of appreciation for the level of complexity or the dynamic nature of the decals can lead to a belief that there is no reason for an error ever occurring. The technical simplicity of the part masks the true regulatory, informational, and process complexity that must be accounted for. A tool such as System Dynamics can help further the understanding of all engineers and management either directly or tangentially involved. It was observed in the interview process that a true understanding and appreciation of the complexities involved often did not occur until after an error occurred. Hopefully, this paper will help to highlight the need for proactive process improvements before further errors develop, as they most surely will.

PART IV – TAKE-AWAYS AND SUGGESTED IMPROVEMENTS

Chapter 11. System Dynamics Lessons

The emission decal design and release process tends to be a knowledge intensive process in which the information is difficult to explicitly describe. This makes the processes difficult to manage with all of the necessary information transfers. Formal modeling techniques such as System Dynamics overcomes some of the shortcomings of earlier techniques, such as the static nature of CPM's and the missing underlying processes of DSM's. System Dynamics can help management understand the inherent problems and design ways to overcome them.

For emission decals, we saw that the enemy is late change (all changes Post Job #1). Recall campaigns and real cost to the company were both significantly increased by the additional stock of Post Job #1 (late) changes. However important it is to minimize the number of changes, late change is a reality of today's product development processes. Better methods are necessary to more effectively process these late changes. Although ideal methodology improvements are preventative, we also saw that a measure of effective checking is required to help mitigate number and severity of recall campaigns.

11.1. Late Changes are the Enemy

Through interviews and looking at the recent growth of recall campaigns, it became very clear that the relative explosion in Post J#1 coordinated changes have significantly contributed to a cost growth associated with an increase in recall campaigns. For the five-year period of 1998-2002 for one OEM, direct emission decal campaign costs averaged $160K per year. However, for the period of 2000-2003, this same OEM estimates that the annual direct cost of emission decal campaigns has almost doubled to $300K. This may seem like a small sum for a Fortune 100 company, but the percent increase is troubling as is the fact that 'cost' to the company goes beyond just monetary cost as was discussed earlier. Also affected is public perception of the company, etc. Although many factors have played a role and are included in the System Dynamics model, late changes have added extra work, stress, and opportunity for error. It should be clear from these models that late changes should be minimized wherever possible. The engineering release system, in which the emission decals are just one part, was not developed with this constant 'churn' envisioned. When developed, the release system was designed with the intent to release parts for each model year, but with very little change during an individual model year. These late changes especially tax a process such as the emission decal design and release process with high informational and process complexity, requiring a high degree of cooperation and manual data transfer. Obvious ways to combat this are to only make late changes when absolutely necessary (reducing the Late Job Scope in the vensim model), and to better automate the entire engineering release system (increasing quality percentage for each step from the high 90's to practically 100). In the case of emission decals, this automation must encompass the entire process from data input to installation on vehicles. The investment required for such an undertaking is not well understood by any person interviewed; however, consensus was that the cost of just the IT programming would far exceed the $300K in today's annual recall cost.

11.2. Individual Experts Do Not Necessarily Make a Quality System

It became apparent when developing the System Dynamics model that the current quality of individual, largely manual, steps in the emission decal design and release process is very high, general running in excess of 97% accurate. It was not uncommon to have individual steps at greater than 99% quality. Numbers presented in section 5.1 even calculated the accuracy of emission decal design to be at the 5-sigma level. However, handoffs between different functional experts or across organizations are often mishandled. For coordinated changes, often the processor or catalyst release engineers do not always communicate with the emission decal engineers. For the second case, the new team releasing the fan warning labels did not communicate with the former team nor did they communicate with the Office of General Counsel. For the third case, there was a general communication breakdown between engineering and manufacturing compounded by an installation error. In general, for each of these cases examined in Part III, individuals accurately performed the tasks that they had been traditionally assigned in their functional silos. Design engineers designed, release writers released, assembly operations installed, etc. Breakdowns occurred when the job experience level and systems understanding fell to a point where individuals could not overcome gaps in the process by utilizing their own formal and informal information networks to achieve the desired results. If individuals only did what they believed to be their job and then 'threw it over the wall', system errors naturally followed. This is a frightening realization when one remembers that the maximum fine is $27,500 per vehicle and one decal could potentially be used thousands of times before an error is uncovered.

11.3. 'Value' of Additional Commitments

As informational complexity of the emission decals only seems to be increasing, it will be necessary for a team of experts to better automate the process from data input to decal installation in order to drive down campaign costs. A heavyweight team could be used in this capacity. However, the low relative cost of the campaigns ($160K-$300K per year) and the need for a 1-year payback period put a limit on resources that can be used. Instead, many of the individual vehicle teams are using non-automated means to try to track progress, issues, and to proactively resolve these issues before emergencies arise. This by itself does not improve accuracy. These low-cost attempts instead may end up costing an OEM more money by causing enough interruptions to not allow all the necessary work to be completed in the time allotted. This could result in slipped schedule, but more likely it would result in rushed task completion that is more prone to error.

11.4. Need for Systems Understanding at All Levels

Many of the past emission decal problems have arisen due to experts in one field not having a thorough understanding of the entire design and release process from data input all the way to decal installation. Furthermore, limited systems understanding on the part of the experts' management has resulted in poor fixes, more stress, a perceived lack of support, and higher turnover rate of the experts. Stress, management support, and time on the job are all included in the vensim model. Each of these factors plays a significant role in campaign prevention.

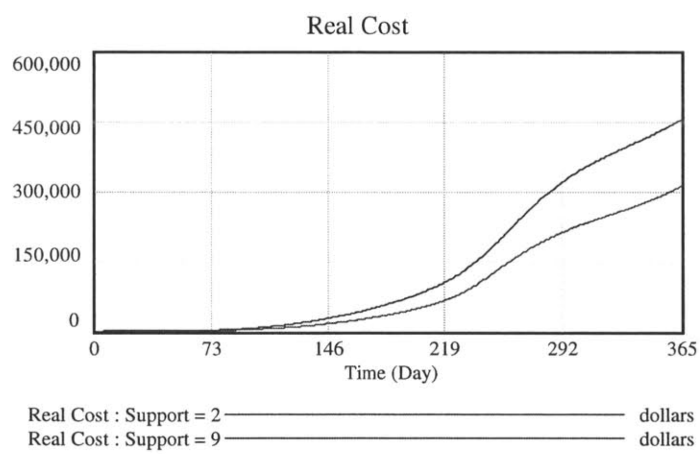


Figure 50. Management support of the emission decal design and release engineers rated on a 1-10 scale (1 low, 10 high). This run used the fully developed model from Chapter 10.

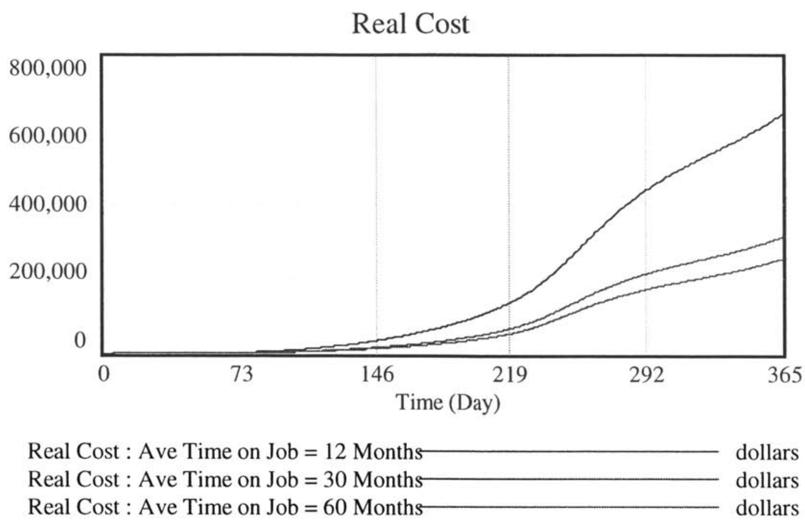


Figure 51. These runs use the fully developed model of Chapter 10 and look at the different values of average time on the job of the emission decal design and release engineers. Notice the large impact if the average experience falls to 12 months.

In today's economic environment of consolidations and organizational 'flattening', numerous management role employees have been displaced from their previous assignments, but have not been let go. Instead, these displaced management role employees are often underutilized in special assignment roles and are in need of a new permanent assignment. As properly trained, technically and process mature management move to new positions, the tendency is to backfill with current management role employees who may or may not have a thorough understanding of the process. The mindset of upper management needs to evolve so that process understanding and process maturity are seen and necessary rather than incidental. Owen D. Young says "it is not the crook in modern business that we fear, but the honest man that does not know what he is doing".[32]

Chapter 12. Recommended Process Improvements

Returning to the regulatory, informational, and process complexity of Part II, several items stand out as possible process improvements to be investigated further. Many of these have been mentioned before at the various OEM's, but have either been deemed too difficult to get approved or have been negatively impacted by corporate inertia (i.e. attachment to the status quo).

12.1. Work as Industry to Eliminate

Most of the information available on emission decals is available by other means such as service manuals, regulatory agency databases, owners' guides, etc. The value of the emission decal has been called into question. Other than government agencies and in-use testing stations, it in unclear if any other customers ever look at their emission decal. And for these users, it would be possible to code most of the pertinent information into the onboard computer that controls the vehicle's functions. This data could then be accessed through the On-Board Diagnostic (OBD) port using a common diagnostic scan tool. However, the "reformer has enemies in all those who profit from the old order"[33]. Many government and industry jobs are associated with the promulgation and adherence to regulations. In fact, it has been argued in California that CARB duplicates much of the work of the U.S. EPA and could be eliminated as a way to cut costs and help balance the California budget. Complete elimination of the underhood emission decal is a worthy goal for Industry, but may be a long-term solution at best.

Although many in Industry have voiced support for this idea, larger issues tend to have some of the OEM's shy away from seeking this regulatory relief. Complete elimination would require total support from every major manufacturer.

12.2. Remove All Non-Mandatory Information

In the absence of complete elimination of the emission decal, every effort should be undertaken by individual manufacturers to thrift all non-mandatory information. Removal of non-regulated information would reduce the odds of a recall campaign.

12.2.1. Spark Plug Gap

The emission decal regulations specify that "Engine tune-up specifications and adjustments...as well as other parameters deemed necessary by the manufacturer" be included. In previous model years, manufacturers had included both spark plug part numbers and gap information. Some manufacturers believe that spark plugs no longer need to be gapped because of their longer life, so they provide no information on spark plugs on their decals. Other manufacturers still believe that including the gap is appropriate. It is highly recommended that in order to avoid potential rework and/or errors, all manufacturers apply this test equally and eliminate the spark plug gap information from the decals. Since the decals without the spark plug information has been deemed acceptable by the regulatory agencies (it has not been a subject of recall), there is little or no legal jeopardy for others with its elimination. At the same time, it eliminates one source of possible late change even if all initial information is correct.

For those manufacturers that still show the spark plug gap, it has been stated that the customer service divisions (those tasked to deal directly with service providers) have long appealed to have this information retained. These divisions tend to have a significant say since they tend to show a profit to the bottom line. Again, the issue may need to be elevated to a high enough level to make a firm policy decision.

12.2.2. Federal Emission Levels in Compliance Language

As was mentioned in section 3.1, 40 CFR §86.1807-01 of the Federal regulations provides an important proviso to the legal requirement that manufacturers include the certification and in-use emission levels in the compliance language text of the emission decal: "In lieu of this requirement [to include exhaust emission standards], manufacturers may use the standardized test group name designated by EPA". This is an important distinction. The complexity of Federal Tier I and Tier II emission standards (seen in Appendix A) provides an opportunity for those manufacturers who do not follow this provision to create a recallable decal error. Moreover, even if all information is initially correct, a late change may precipitate a change to the Federal emission levels. It may be theoretically possible, if not already certified, to use the existing decals and certify to the new level. Manufacturers who do not utilize this provision are only making life more difficult on themselves, because as we have seen, late changes are often unavoidable in the current business environment.

The only possible explanations for this added requirement are an incomplete understanding of the regulatory complexity and/or a failure of the regulatory interfaces to communicate effectively with the design teams.

12.2.3. Fuel Type

As was mentioned in section 6.5, Federal regulations state that "vehicles designed to be capable of operating on fuels other than gasoline or diesel, the statement ``This vehicle is certified to operate on [specify fuel(s)]''"[34] must be included on the decal. No attempt should be made to go above and beyond the stated requirement and specify which type of certification gasoline was utilized. Any effort to do so will ultimately increase the recall jeopardy. Clearly the regulators know how to promulgate new regulations, so if they truly believe that additional information is necessary, they need to write that requirement into law so that all manufacturers are required to comply.

Regulatory interfaces who do not design the decals may not recognize the additional complications that could result from such an agreement. This incomplete systems understanding tends to drive agreements where the consequences are not always well understood.

12.2.4. Courtesy Copy

The requirement for engine certified products is to provide an emissions decal on the engine itself. Ford chooses to provide a courtesy copy on the vehicle chassis to ensure readability at an additional cost of approximately $0.20-$0.25 per vehicle in material cost alone. This is not required by regulation. As the third case study demonstrated, this special handling of two decals for certain heavy-duty applications caused confusion at the assembly plant where installation took place. Even though all decals were designed and released correctly, they were still not installed correctly due to a misunderstanding and a general breakdown in communications. Going above and beyond the regulations is not required nor is it advisable. The potential for error, recall, and additional cost to the company is only increased – not to mention the increased cost of materials and labor.

It is believed that this courtesy copy was originally established in an effort to simplify the vehicle assembly plant process by having the plant install a decal in the same location for every vehicle, regardless of certification type (vehicle or engine). But as engine decal installation was transitioned from the engine assembly plants to the vehicle assembly plants in the past 5 years, it is now time to revisit this additional requirement.

12.3. Standardize Location and Size

The fragmented platform approach of most manufacturers leads to 'perfect' product designs for each vehicle but leads away from what is best for the company as a whole – commonality.

Each vehicle line attempts to work with the design and release team to establish a size, shape, and location that are optimal for that vehicle line. This causes a great deal of iteration, rework, and meetings to permanently establish the size, shape, and location and they are often subject to revision if other changes occur on the vehicle (change to drain or tooling holes, real estate reassigned, etc.). In actuality, the best thing for any company is to establish one or two standard sizes, shapes, and locations. This would alleviate rework cycles, and free the schedule of engineers whose time in meetings only slow down the rate of design work.

This need to standardize has been recognized but difficult to implement because of the relative autonomy afforded every program to develop its own best practices.

12.4. Better Dissemination of Information

The case studies investigated earlier point to two underlying causes for many of the errors and recalls attributed to the emission decal design and release process: late changes and communication breakdowns. Although late changes are clearly undesirable, they are often driven from the highest levels of each company and difficult to eliminate. However, communication and information exchanges can be systematically improved.

12.4.1. Documented Process

The value of experience plays an important role in avoiding potential recall situations. Many times, such as in the missing engine decal example, everything apparently is done correctly and according to procedure. But errors still occur often due to communication breakdowns and inexperienced engineers, Part 1 analysts, release writers, pre-production analysts not knowing who they need to contact to ensure that everything is completed as intended. The computer systems and automatic data feeds do not replace the need for direct communication and cooperation. Communication and both formal and informal networks of individual employees in the process is worthy of additional study.

To capture the experience and networks developed by more experienced employees in every position, the process needs to be better documented and treated as a living document. A heavyweight team could consolidate the information, better demonstrate to less experienced employees how to effectively manipulate the bureaucracy and available resources, and help create a real sense of pride and teamwork where the more experienced can mentor and serve as examples to the less experienced. The lessons learned need to be documented and made available to both the general salary roll to avoid past oversights and management since their 'sphere of influence' to implement change is by definition greater.

12.4.2. Use of Web

Both the Intranet and Internet are powerful tools meant to better facilitate information and data transfer. On a large scale, all information placed on emission decals could be made available to users through the Internet. It is theoretically possible to have all the information provided in a database with the vehicle's Vehicle Identification Number (VIN). This would render the decal itself extraneous and available for deletion through regulatory revision.

On a smaller scale, if the decal itself is maintained, data can be better transferred within each manufacturer by the use of electronic forms. The time required to complete the actual paperwork drains the rate at which new tasks can be accomplished. Instead of paper marked prints being transferred between a manufacturer and decal supplier, prints, approvals and releases could all be handled electronically speeding up the process. Much of the engineers' productivity is limited by the time required to answer similar queries from multiple programs via phone calls, meetings, electronic mail and the like. If standard locations, sizes, shapes, and frequently asked questions (FAQ's) could all be answered on an internal website to which the supplier also has access, productivity for all could potentially be increased significantly.

This chapter has tried to capture improvement suggestions designed to reduce the underlying regulatory, informational, and process complexity that some accept as a 'given'. It is the belief of the author that many potential improvement efforts have been mistakenly written off as too difficult or non-negotiable. Instead, all possible means to reduce the complexity of the task of designing, releasing, and installing correct emission decals should be investigated and should span divisional and organizational boundaries.

Chapter 13. Larger Lessons to be Learned

There are larger lessons to be learned from this paper on the emission decal design and release process. Many of these same issues and improvement suggestions can be extrapolated beyond emission decals. They may seem simple and easily recognizable as this chapter is reviewed, but many of the issues such as communication, systems thinking, and networking are difficult to grasp and develop an actionable plan to implement.

13.1. Communication is Paramount

Communication breakdowns have been identified as the chief underlying cause of emission decal recalls in the past five years. Although it is advisable to minimize the number and impact of late changes, this reduction needs to occur at high levels that fall outside the boundary of this thesis. In the fan warning and engine decal case studies, on the surface everything was designed, released, and produced correctly. Communication breakdowns, whether it was between design groups or between a design group and assembly, were the root cause of the eventual recalls. This need to communicate obviously goes beyond just the design and release of emission decals. Decal difficulties are just a visible manifestation of internal communication disconnects.

Communication could be improved by rewarding and fostering process maturity, i.e. having talented individuals learn the entire process by cycling through different responsibilities. As these key individuals develop a broader perspective, they should be tasked with passing this information on to others.

13.2. Early Identification of Issues is Extremely Important

The earlier that the need for rework can be identified, the less potential for later errors exist. As can be seen for the CPM diagram, much of the work is sequential so early identification of rework will reduce the number of tasks to be redone and the higher the productivity for other jobs that may get pushed aside for an emergency on another program. The DSM shows the shorter circuit of tasks that need to be redone if errors or the need for change can be identified early.

Although checking the work of others is not ideal, it is absolutely necessary and needs to be undertaken in a timely and expeditious manner. Likewise, everyone who feeds the emission decal, format, and Part 1 processes needs to recognize that their tasks are at the beginning phase of a laborious, time-intensive largely sequential process. If errors in the inputs occur, study needs to be made of what were the root causes of these information errors rather than a study of the checkers or attaching blame to the users of this faulty information.

13.3. Nothing is "Too Small" to be Overlooked

One axiom in system dynamics is "small events can have large consequences"[35]. This definitely holds true for the emission decal design and release process and the certification process as a whole. The attention necessary to ensure that the early inputs are correct cannot be overstated. Unfortunately, it is all too common for an engine engineer to believe that a vacuum schematic drawing input is minor and can changed later if necessary. Versions that should be finalized are instead submitted as shoddy rough drafts. This is just one example of technical personnel not taking a systems perspective to the process and instead looking at their task as dissociated from the overall product development process. They do not always understand how their work fits in the bigger picture, leading to poor quality and low morale. Senior engineers need to instruct personnel with less experience, both general salary roll and management, as to where their work fits into the overall process. A special caution is for new management to learn about process implications before implementing change. The enthusiasm to implement improvements can backfire if the ramifications are not completely understood or if they do not manifest themselves immediately.

13.4. Informational Complexity can be Trickier than Technical Complexity

Emission decals are often given a bad reputation because the technical complexity of designing a label is not high. However, as can be seen from the Ford Econoline example, the release complexity can be very exacting. To correctly describe the usage as in the Ford example in such a way that the release writers can accurately code the information, pre-production can order the correct quantity of parts, and assembly to install the correct parts is difficult. This is an informational and process complexity that can be overlooked by those who do not understand the system of both certification and release. Or more accurately, those people who do not possess a systems understanding as taught by the MIT SDM program can oversimplify the process and make incorrect policy decisions.

13.5. Opportunities for Additional Research

As a result of this thesis, several subjects stand out as potentials for further research. First, System Dynamics could be used to further disaggregate the models developed earlier to provide more detailed results and insights into the emission decal design and release process. Second, formal System Dynamics modelling could be used to gain deeper into the entire certification process and the effect of late changes on more than just the decal process, but also the engineering, development, and testing staffs. Third, since communication was seen to play an integral role in this product development process, it would be logical to study both the formal and informal networks of productive, experienced engineers to see how the skills they had developed could be translated to other areas.

Figures

Tables

Appendices

Appendix A – Federal and California Emission Standards

Federal Tier I

CERTIFICATION TAILPIPE EMISSION STANDARDS (g/mile) FEDERAL PASSENGER CAR									
Gasoline/NG/Methanol/Ethanol*/Diesel/LPG								Diesel	
	THC	NMHC	NMOG	CO	NOx**	PM**	HCHO	NOx	PM
Tier 1	0.41	0.25 (0.31)	–	3.4 (4.2)	0.4 (0.6)	0.08 (0.10)	–	1.0 (1.25)	0.08 (0.10)
TLEV	0.41	–	0.125 (0.156)	3.4 (4.2)	0.4 (0.6)	0.08 (0.10)	0.015 (0.018)	0.4 (0.6)	(0.08)
LEV	0.41	–	0.075 (0.090)	3.4 (4.2)	0.2 (0.3)	0.08 (0.10)	0.015 (0.018)	0.2 (0.3)	(0.08)
ULEV	0.41	–	0.040 (0.055)	1.7 (2.1)	0.2 (0.3)	0.08 (0.10)	0.008 (0.011)	0.2 (0.3)	(0.04)

CERTIFICATION TAILPIPE EMISSION STANDARDS (g/mile) LIGHT LIGHT-DUTY TRUCKS (≤ 6000 LBS. GVWR)									
Gasoline/NG/Methanol/Ethanol*/Diesel/LPG								Diesel	
	THC	NMHC	NMOG	CO	NOx **	PM **	HCHO	NOx	PM
LDT1 (≤ 3750 LVW)									
Tier 1	[0.80]	0.25 (0.31)	-	3.4 (4.2)	0.4 (0.6)	0.08 (0.10)	-	1.0 (1.25)	0.08 (0.10)
TLEV	[0.80]	-	0.125 (0.156)	3.4 (4.2)	0.4 (0.6)	0.08 (0.10)	0.015 (0.018)	0.4 (0.6)	(0.08)
LEV	[0.80]	-	0.075 (0.090)	3.4 (4.2)	0.2 (0.3)	0.08 (0.10)	0.015 (0.018)	0.2 (0.3)	(0.08)
ULEV	[0.80]	-	0.040 (0.055)	1.7 (2.1)	0.2 (0.3)	0.08 (0.10)	0.008 (0.011)	0.2 (0.3)	(0.04)
LDT2 (3751-5750 LVW)									
Tier 1	[0.80]	0.32 (0.40)	-	4.4 (5.5)	0.7 (0.97)	0.08 (0.10)	-	(0.97)	0.08 (0.10)
TLEV	[0.80]	-	0.160 (0.200)	4.4 (5.5)	0.7 (0.9)	0.08 (0.10)	0.018 (0.023)	0.7 (0.9)	0.08 (0.10)
LEV	[0.80]	-	0.100 (0.130)	4.4 (5.5)	0.4 (0.5)	0.08 (0.10)	0.018 (0.023)	0.4 (0.5)	0.08 (0.10)
ULEV	[0.80]	-	0.050 (0.070)	2.2 (2.8)	0.4 (0.5)	0.08 (0.10)	0.009 (0.013)	0.4 (0.5)	(0.05)

Federal Tier II

CERTIFICATION TAILPIPE EMISSION STANDARDS (g/mile)
TIER 2 STANDARD BINS FOR PCs & LDT2s
FEDERAL PASSENGER CAR, LDT1, & LDT2

Bin#	NOx	NMOG	CO	HCHO	PM*	Note
10	0.4(0.6)	0.125(0.156)	3.4(4.2)	0.015(0.018)	(0.08)	a, b
9	0.2(0.3)	PC/LDT1: 0.075(0.090) LDT2: 0.100(0.130)	3.4(4.2)	0.015(0.018)	(0.06)	a, b
8	0.14(0.20)	0.100(0.125)	3.4(4.2)	0.015(0.018)	(0.02)	
7	0.11(0.15)	0.075(0.090)	3.4(4.2)	0.015(0.018)	(0.02)	
6	0.08(0.10)	0.075(0.090)	3.4(4.2)	0.015(0.018)	(0.01)	
5	0.05(0.07)	0.075(0.090)	3.4(4.2)	0.015(0.018)	(0.01)	
4	(0.04)	(0.070)	(2.1)	(0.011)	(0.01)	
3	(0.03)	(0.055)	(2.1)	(0.011)	(0.01)	
2	(0.02)	(0.010)	(2.1)	(0.004)	(0.01)	
1	(0.00)	(0.000)	(0.0)	(0.000)	(0.0)	

TIER 2 & INTERIM NON-TIER 2 STANDARD BINS
FEDERAL LDT3, LDT4, & MDPV

Bin#	NOx	NMOG	CO	HCHO	PM*	Note
11	0.6(0.9)	0.195(0.280)	5.0(7.3)	0.022(0.032)	(0.12)	a.b
10	0.4(0.6)	LDT3: 0.160(0.230) LDT4/MDPV: 0.195(0.280)	4.4(6.4)	0.018(0.027)	(0.08)	a,c
9	0.2(0.3)	0.140(0.180)	3.4(4.2)	0.015(0.018)	(0.06)	a,c
8	0.14(0.20)	0.125(0.156)	3.4(4.2)	0.015(0.018)	(0.02)	d
7	0.11(0.15)	0.075(0.090)	3.4(4.2)	0.015(0.018)	(0.02)	
6	0.08(0.10)	0.075(0.090)	3.4(4.2)	0.015(0.018)	(0.01)	
5	0.05(0.07)	0.075(0.090)	3.4(4.2)	0.015(0.018)	(0.01)	
4	(0.04)	(0.070)	(2.1)	(0.011)	(0.01)	
3	(0.03)	(0.055)	(2.1)	(0.011)	(0.01)	
2	(0.02)	(0.010)	(2.1)	(0.004)	(0.01)	
1	(0.00)	(0.000)	(0.0)	(0.000)	(0.0)	

California LEV I

Exhaust Mass Emission Standards for New 2001 - 2003 Model Year Tier 1 Vehicles and TLEV Passenger Cars and Light-Duty Trucks; 2001 - 2006 Model Year LEV I LEV and ULEV Passenger Cars and Light-Duty Trucks; 2001-2003 Model Year Tier 1 Medium-Duty Vehicles; and 2001-2006 Model Year LEV I LEV, ULEV and SULEV Medium-Duty Vehicles							
Vehicle Type	Durability Vehicle Basis (mi.)	Vehicle Emission Category	NMOG (g/mi)	Carbon Monoxide (g/mi)	Oxides of Nitrogen (g/mi)	Formaldehyde (mg/mi)	Particulate from diesel vehicles** (g/mi)
All PCs; LDTs (0-3750 lbs. LVW)	50,000	Tier 1	0.25*	3.4	0.4	n/a	0.08
		TLEV	0.125	3.4	0.4	15	n/a
		LEV	0.075	3.4	0.2	15	n/a
		ULEV	0.040	1.7	0.2	8	n/a
	100,000	Tier 1	0.31	4.2	0.6	n/a	n/a
		Tier 1 - diesel option	0.31	4.2	1.0	n/a	n/a
		TLEV	0.156	4.2	0.6	18	0.08
		LEV	0.090	4.2	0.3	18	0.08
		ULEV	0.055	2.1	0.3	11	0.04
LDTs (3751-5750 lbs. LVW)	50,000	Tier 1	0.32	4.4	0.7	n/a	0.08
		TLEV	0.160	4.4	0.7	18	n/a
		LEV	0.100	4.4	0.4	18	n/a
		ULEV	0.050	2.2	0.4	9	n/a
	100,000	Tier 1	0.40	5.5	0.97	n/a	n/a
		TLEV	0.200	5.5	0.9	23	0.10
		LEV	0.130	5.5	0.5	23	0.10
		ULEV	0.070	2.8	0.5	13	0.05
MDVs (3751-5750 lbs. ALVW)	50,000	Tier 1	0.32	4.4	0.7	18	n/a
		LEV	0.160	4.4	0.4	18	n/a
		ULEV	0.100	4.4	0.4	9	n/a
		SULEV	0.050	2.2	0.2	4	n/a
	120,000	Tier 1	0.46	6.4	0.98	n/a	0.10
		LEV	0.230	6.4	0.6	27	0.10
		ULEV	0.143	6.4	0.6	13	0.05

		SULEV	0.072	3.2	0.3	13	0.05

Vehicle Type	Durability Vehicle Basis (mi.)	Vehicle Emission Category	NMOG (g/mi)	Carbon Monoxide (g/mi)	Oxides of Nitrogen (g/mi)	Formaldehyde (mg/mi)	Particulate from diesel vehicles** (g/mi)
MDVs (5751-8500 lbs. ALVW)	50,000	Tier 1	0.39	5.0	1.1	22	n/a
		LEV	0.195	5.0	0.6	22	n/a
		ULEV	0.117	5.0	0.6	11	n/a
		SULEV	0.059	2.5	0.3	6	n/a
	120,000	Tier 1	0.56	7.3	1.53	n/a	0.12
		LEV	0.280	7.3	0.9	32	0.12
		ULEV	0.167	7.3	0.9	16	0.06
		SULEV	0.084	3.7	0.45	8	0.06
MDVs 8501 -10,000 lbs. ALVW	50,000	Tier 1	0.46	5.5	1.3	28	n/a
		LEV	0.230	5.5	0.7	28	n/a
		ULEV	0.138	5.5	0.7	14	n/a
		SULEV	0.069	2.8	0.35	7	n/a
	120,000	Tier 1	0.66	8.1	1.81	n/a	0.12
		LEV	0.330	8.1	1.0	40	0.12
		ULEV	0.197	8.1	1.0	21	0.06
		SULEV	0.100	4.1	0.5	10	0.06
MDVs 10,001-14,000 lbs. ALVW	50,000	Tier 1	0.60	7.0	2.0	36	n/a
		LEV	0.300	7.0	1.0	36	n/a
		ULEV	0.180	7.0	1.0	18	n/a
		SULEV	0.09	3.5	0.5	9	n/a
	120,000	Tier 1	0.86	10.3	2.77	n/a	n/a
		LEV	0.430	10.3	1.5	52	0.12
		ULEV	0.257	10.3	1.5	26	0.06
		SULEV	0.130	5.2	0.7	13	0.06

LEV II Exhaust Mass Emission Standards for New 2004 and Subsequent Model LEVs, ULEVs, and SULEVs in the Passenger Car, Light-Duty Truck and Medium-Duty Vehicle Classes

Vehicle Type	Durability Vehicle Basis (mi)	Vehicle Emission Category	NMOG (g/mi)	Carbon Monoxide (g/mi)	Oxides of Nitrogen (g/mi)	Formaldehyde (mg/mi)	Particulates (g/mi)
All PCs; LDTs 8,500 lbs. GVW or less Vehicles in this category are tested at their loaded vehicle weight.	50,000	LEV	0.075	3.4	0.05	15	n/a
		LEV, Option 1	0.075	3.4	0.07	15	n/a
		ULEV	0.040	1.7	0.05	8	n/a
	120,000	LEV	0.090	4.2	0.07	18	0.01
		LEV, Option 1	0.090	4.2	0.10	18	0.01
		ULEV	0.055	2.1	0.07	11	0.01
		SULEV	0.010	1.0	0.02	4	0.01
	150,000 (optional)	LEV	0.090	4.2	0.07	18	0.01
		LEV, Option 1	0.090	4.2	0.10	18	0.01
		ULEV	0.055	2.1	0.07	11	0.01
		SULEV	0.010	1.0	0.02	4	0.01
MDVs 8,501 - 10,000 lbs. GVW Vehicles in this category are tested at their adjusted loaded vehicle weight.	120,000	LEV	0.195	6.4	0.2	32	0.12
		ULEV	0.143	6.4	0.2	16	0.06
		SULEV	0.100	3.2	0.1	8	0.06
	150,000 (Optional)	LEV	0.195	6.4	0.2	32	0.12
		ULEV	0.143	6.4	0.2	16	0.06
		SULEV	0.100	3.2	0.1	8	0.06

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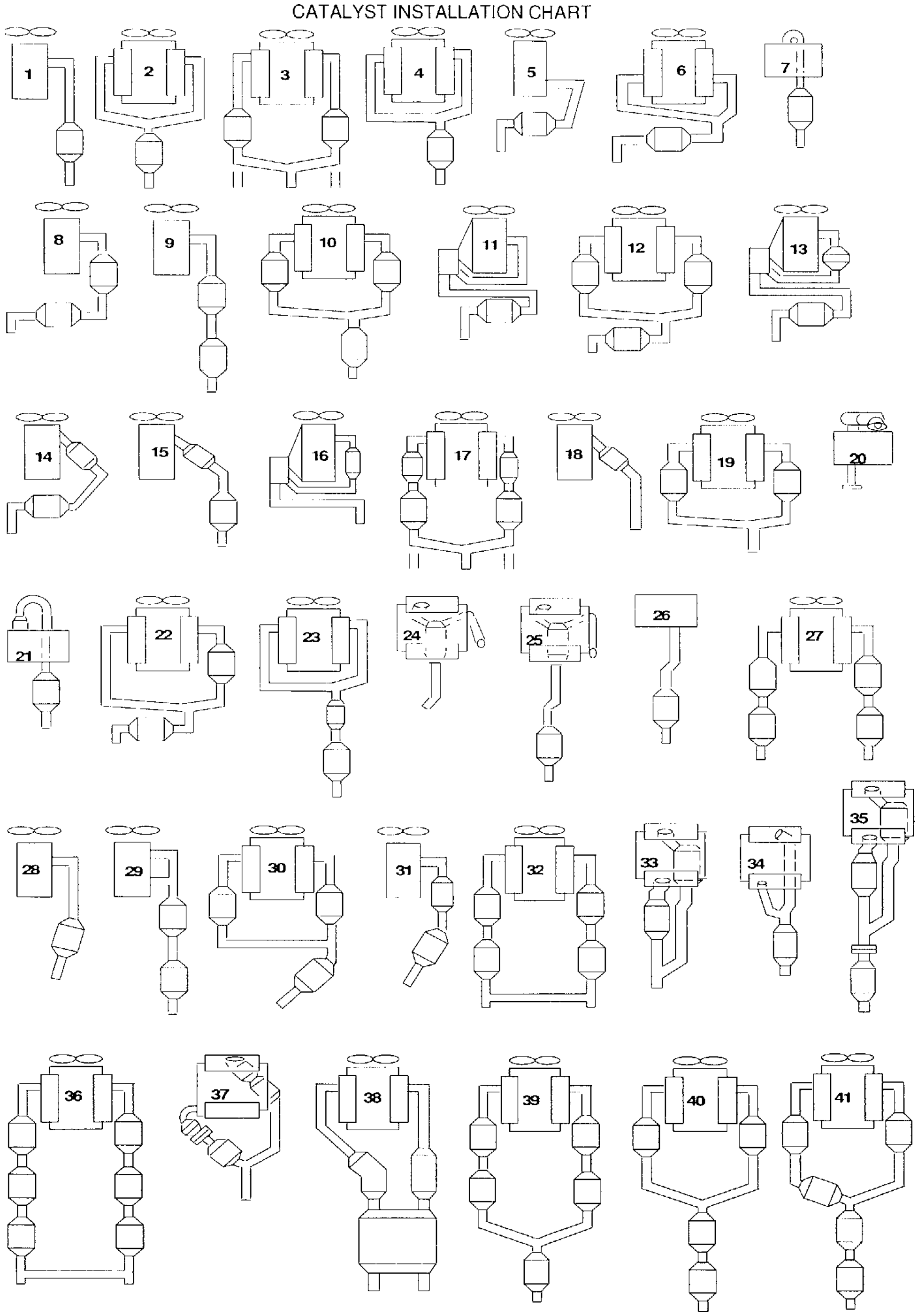
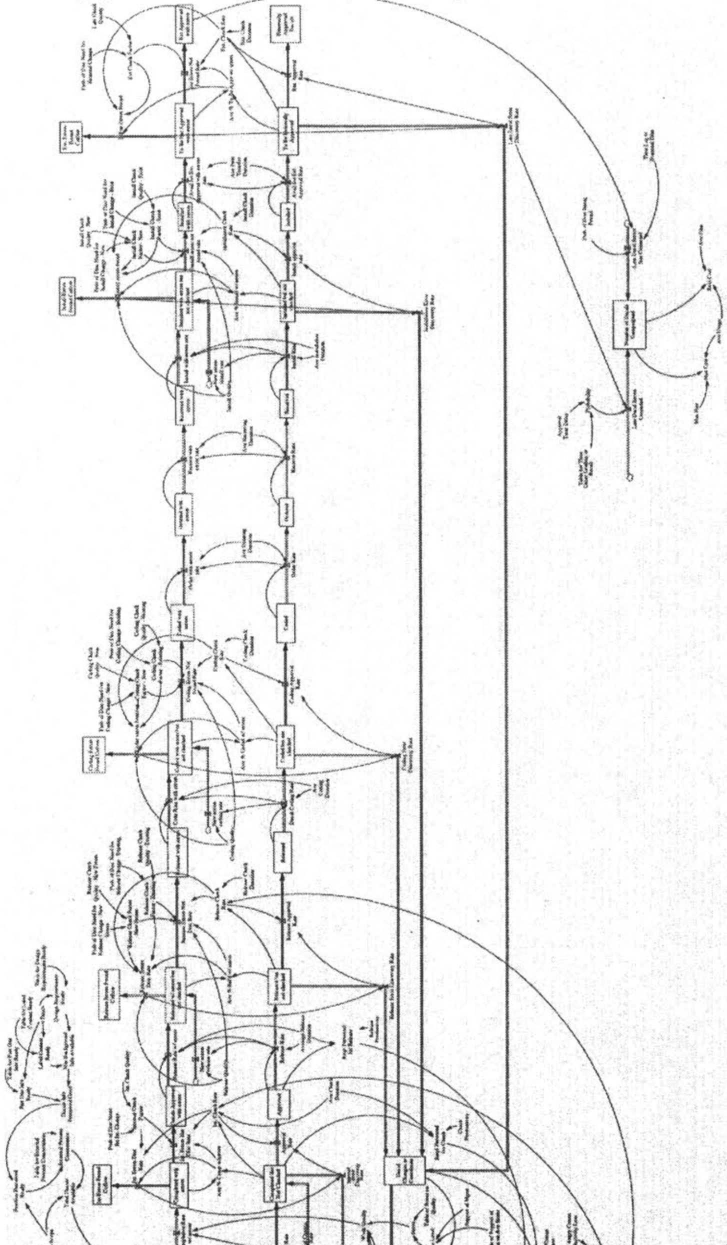
Vehicle Type	Durability Vehicle Basis (mi)	Vehicle Emission Category	NMOG (g/mi)	Carbon Monoxide (g/mi)	Oxides of Nitrogen (g/mi)	Formaldehyde (mg/mi)	Particulates (g/mi)
MDVs 10,001-14,000 lbs. GVW Vehicles in this category are tested at their adjusted loaded vehicle weight.	120,000	LEV	0.230	7.3	0.4	40	0.12
		ULEV	0.167	7.3	0.4	21	0.06
		SULEV	0.117	3.7	0.2	10	0.06
	150,000 (Optional)	LEV	0.230	7.3	0.4	40	0.12
		ULEV	0.167	7.3	0.4	21	0.06
		SULEV	0.117	3.7	0.2	10	0.06

Appendix B – Catalyst Configurations

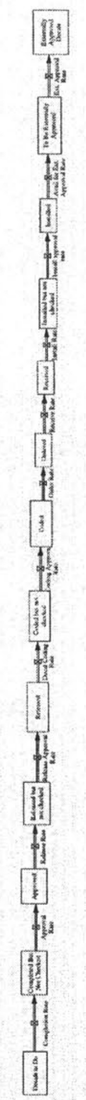
CATALYST INSTALLATION CHART



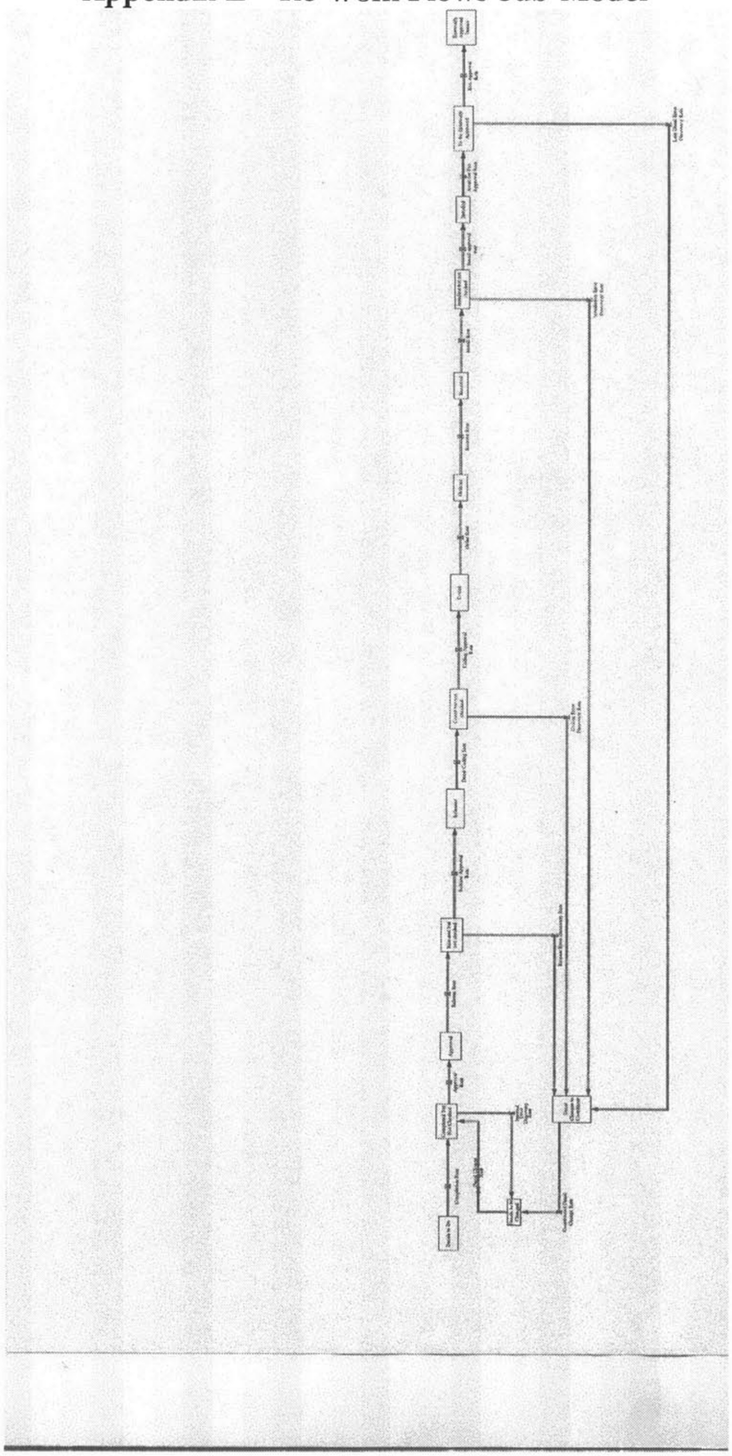
Appendix C – Base System Dynamics Model



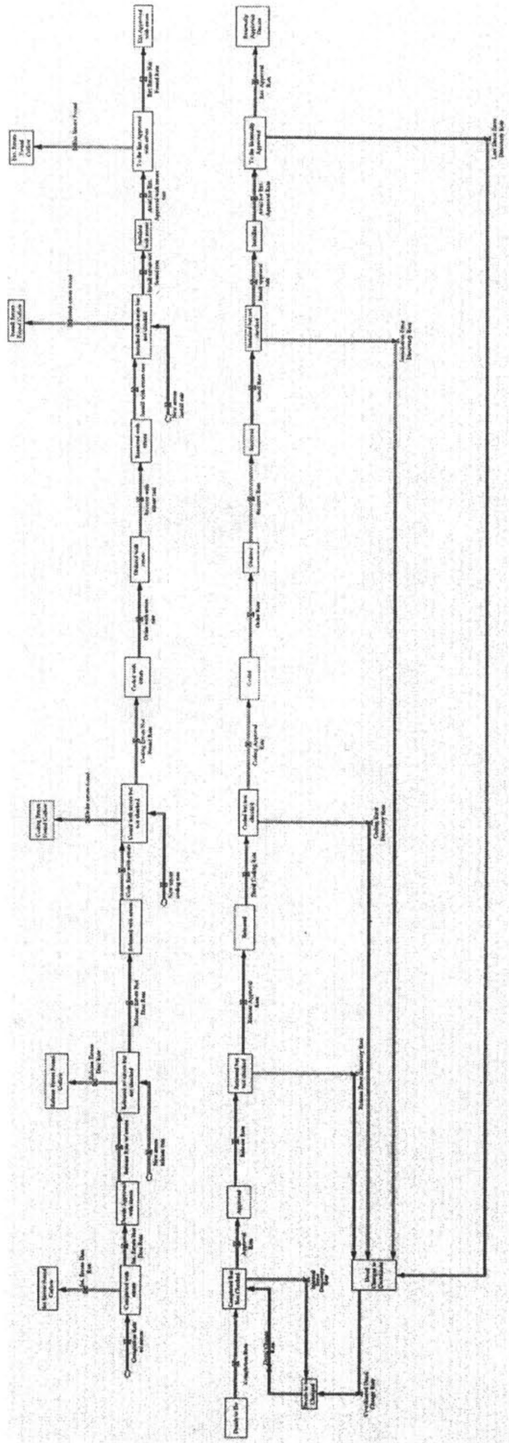
Appendix D – Main Flow Sub-Model



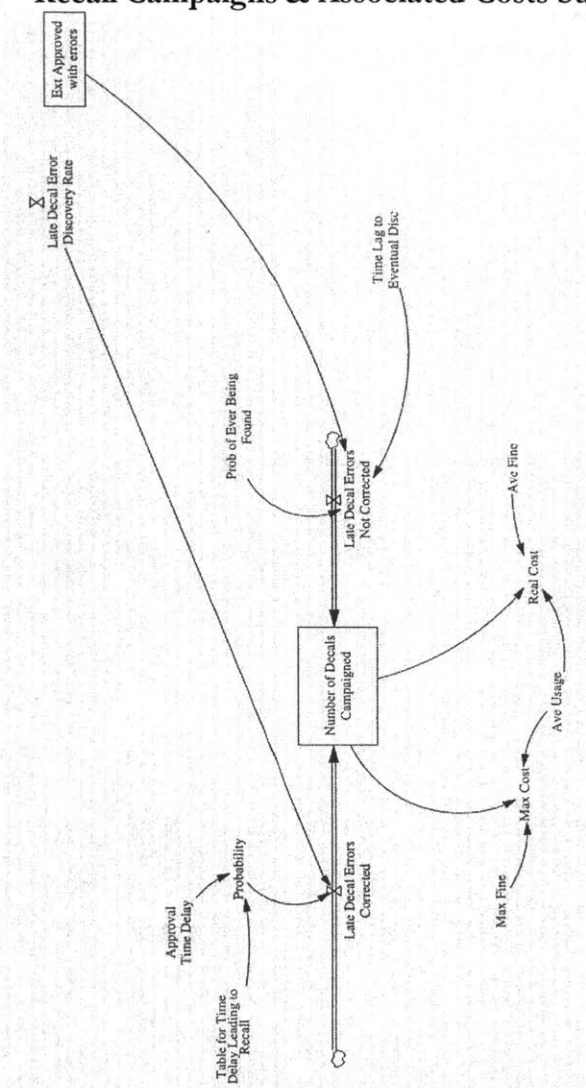
Appendix E – Re-Work Flows Sub-Model



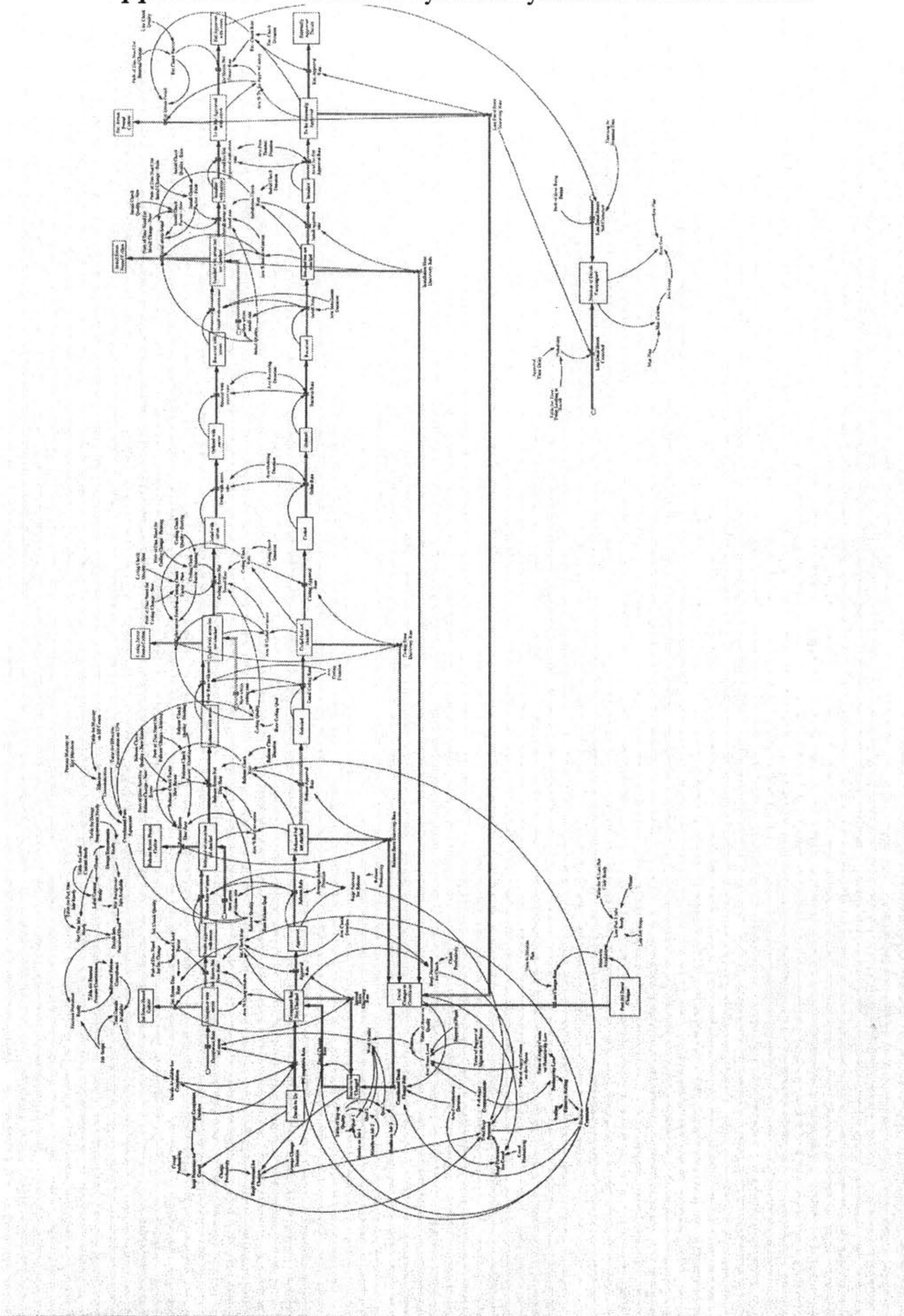
Appendix F – Co-Flows Sub-Model



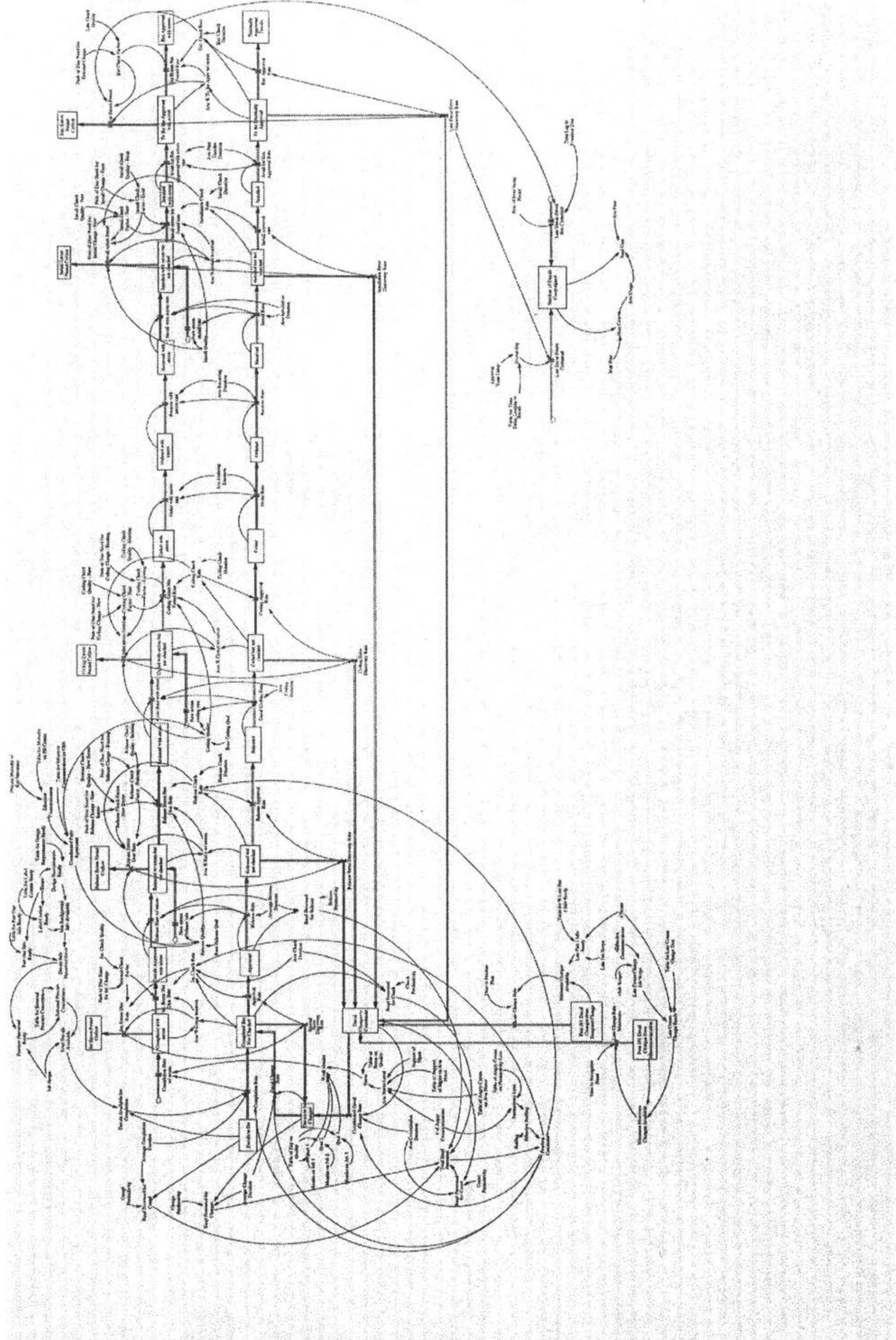
Appendix G – Recall Campaigns & Associated Costs Sub-Model



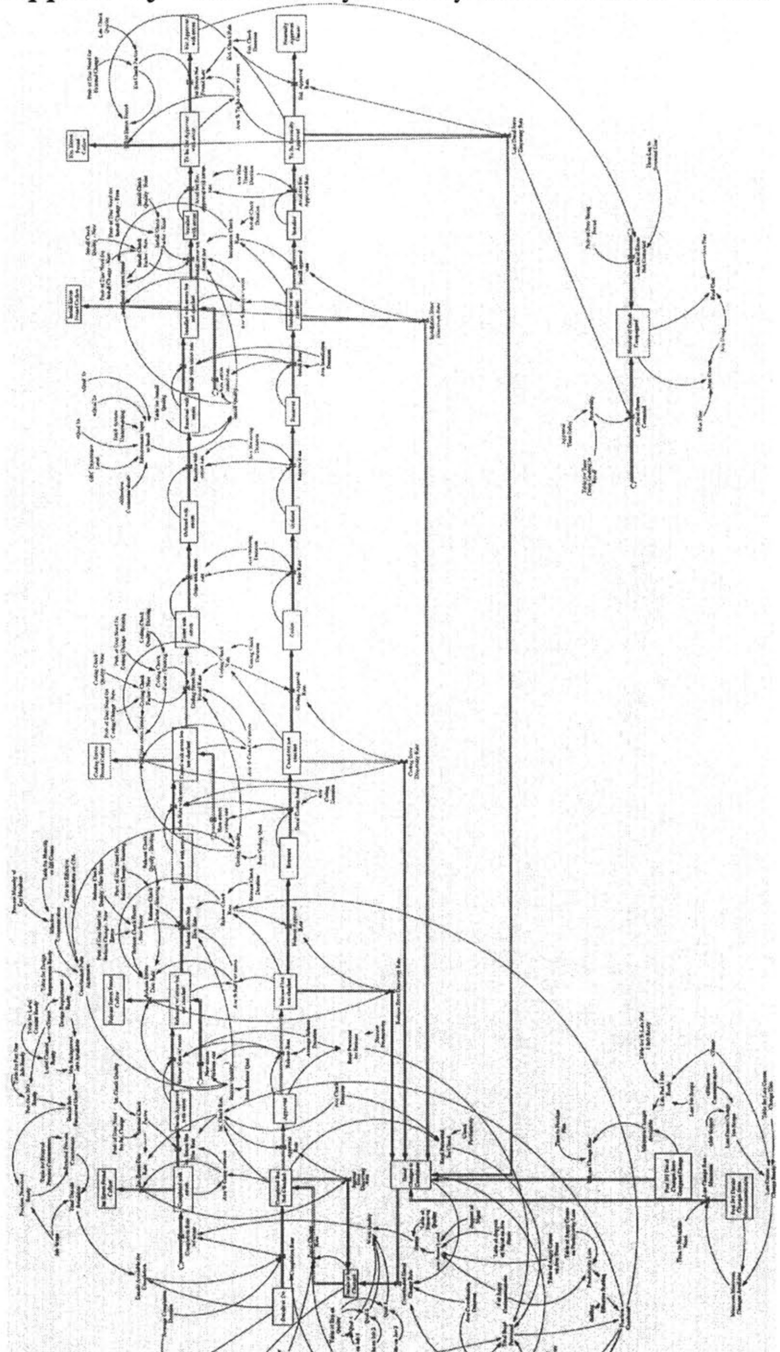
Appendix H – Modified System Dynamics Model: Case 1



Appendix I – Modified System Dynamics Model: Case 2



Appendix J – Modified System Dynamics Model: Case 3



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