# A De-Proliferation Methodology for the Automotive Industry

by

William Giacomo Fonte

B.S. Electrical Engineering, University of Rochester (1985)
B.S. Optical Engineering, University of Rochester (1985)

Submitted to the MIT Sloan School of Management and
the Department of Mechanical Engineering
in Partial Fulfillment of the Requirements for the Degrees of

Master of Science in Management

and

Master of Science in Mechanical Engineering

In conjunction with the Leaders for Manufacturing Program
at the
Massachusetts Institute of Technology
May 1994



Signature of Author ______________________________
Department of Mechanical Engineering
MIT Sloan School of Management
May 6, 1994

Certified by ______________________________
Thomas W. Eagar, Professor of Materials Engineering
Thesis Supervisor

Certified by ______________________________
Karl T. Ulrich, Associate Professor of Management
Thesis Supervisor

Certified by ______________________________
Ain A. Sonin, Professor of Mechanical Engineering
Chairman, Department Committee
Thesis Reader

Accepted by ______________________________
Jeffrey A. Barks, Associate Dean, Master's and Bachelor's Programs

# A De-Proliferation Methodology for the Automotive Industry

by

William Giacomo Fonte

Submitted to the Departments of Mechanical Engineering and Management on May 6, 1994, in partial fulfillment of the requirements of the Degrees of Master of Science in Management and Masters of Science in Mechanical Engineering

## ABSTRACT

General Motors North American Truck Platforms (NATP) has identified the need to reduce product complexity through product de-proliferation as a strategic means to produce higher quality products at lower cost. This thesis presents a de-proliferation methodology based on perceived customer values and the impact of product features on organizational performance. The study addresses both short- and long-term de-proliferation. In the short term, the focus is on eliminating dysfunctional variety (*i.e.*, that perceived by the customer as valueless). The long-term objective is to offer product options that meet customers' desired level of variety but have a low impact on organizational complexity, thereby maximizing profits.

A case study of a representative de-proliferation of rear axles on full-size pickup trucks is used to illustrate the process delineated by this presentation. The rear axle de-proliferation effort at North American Truck Platforms eliminated 67 of 131 axles. The projected life-cycle savings of de-proliferating rear axles was estimated to be $82 million. This study offers a process for extending the de-proliferation of rear axles to all truck components.

Thesis Supervisors:

Dr. Thomas W. Eagar
Professor of Materials Engineering

Dr. Karl T. Ulrich
Professor of Management

## ACKNOWLEDGEMENTS

To my parents, brothers and friends

who

like the north star

provide me with unfailing guidance

★

My thanks to John P. Gaydash, Alan W. Nealley, and Aaron P. Stubbs at General Motors North American Truck Platforms; George B. Sloan, and Edward J. Sullivan at Pontiac East Assembly Plant; Rebecca S. Corrin at General Motors Worldwide Purchasing; Franklin Quan, Tom W. Eagar, Donald B. Rosenfield, and Karl T. Ulrich at MIT who supported and helped shape the ideas contained herein.

Special thanks to Aaron P. Stubbs, and Donald J. Ortner, Jr. for there editorial suggestions of the initial draft of this thesis.

Special thanks also to Jamie Hsu of General Motors for his continued support.

The author would like to acknowledge the MIT Leaders for Manufacturing Program and the General Motors Corporation for their support of this work.

# TABLE OF CONTENTS

# 1. INTRODUCTION

## *1.1 OVERVIEW OF THE RESEARCH PROJECT*

### *Problem Statement*

Within the General Motors North American Truck Platforms (NATP), the value of reducing product complexity has been increasingly recognized by those involved in both manufacturing and marketing. The current level of complexity has precluded high-quality, cost-effective management. The world-class competitors manage complexity effectively to facilitate business practices that produce higher quality products at lower cost, and also strive to reduce complexity wherever possible.

An organization must balance its capabilities against the range and variety of its products. A company's ability to provide high-quality products depends upon its recognizing its limitations. The functional strategies of the different parts of the organization must be integrated so that no one is overwhelmed or unable to meet customer expectations.

The mismatch between manufacturing, marketing and distribution capabilities in the full-size pickup truck market illustrates the importance of coordinated functional strategies. For example, current NATP order management philosophy presupposes that customers value the ability to tailor-make their own unique trucks. The fact that most people, however, buy trucks right out of dealers' inventory and therefore never exercise the option of customizing their own vehicle undermines this philosophy. In the case of rear axles, customers purchasing Chevrolet/GMC full-size pickups have a choice of over 131 rear axles spread across 55 model variants. Unfortunately, the 70% of the customers who purchase their vehicles from the pre-ordered inventory at a dealer actually have only one or two axle choices with certain pickup color and trim combinations. The ability of the assembly plant to supply variety has greatly outstripped the ability of the marketing and distribution system to pass that variety on to the customer. There is some variation in orders nationwide, but not the kind provided for by the existing policy. Dealer orders tend to vary by region, but they are stable within each region. Rather than focus NATP's business systems and marketing practices almost entirely on meeting the requirements for individual customers to specify orders, these systems should focus on regional and lifestyle variations.

Under the present policy, the plant must be able, if requested, to build any of millions of variants. The current Chevrolet/GMC full-size pickup truck has so many features available that it would be theoretically possible to operate an assembly plant for thousands of years without building the same truck twice. Yet in practice, NATP so rarely faces a consistent demand for product variety combinations that it has continued to organize for a high-volume standardized product. However, these extraordinary variety levels do negatively effect manufacturing plant capacity due to line balancing inefficiencies, complex logistics (*e.g.*, supplier, and material handling), and quality deterioration. Figure 1 illustrates the effect of the marketing-manufacturing-distribution mismatch, which constrains plant capacity and results in unused manufacturing, marketing, and engineering variety costs. The unused variety results from (1) the inability of the marketing-manufacturing-distribution system to provide variety choices to the customer in a timely fashion and (2) due to existing dysfunctional variety that no longer meets the needs of the customer. The more variety the division tries to provide, the fewer units it can produce per year because of the effects of idle time, labor inefficiencies, and work-load balancing. In the case where customer demand exceeds capacity, revenue is lost. NATP has expended much effort on product simplification for a long time. Unfortunately, little or no progress has been made in managing complexity, much less in reducing it. Given present market conditions, the company must come to grips with the efficient rationalization of its product line.

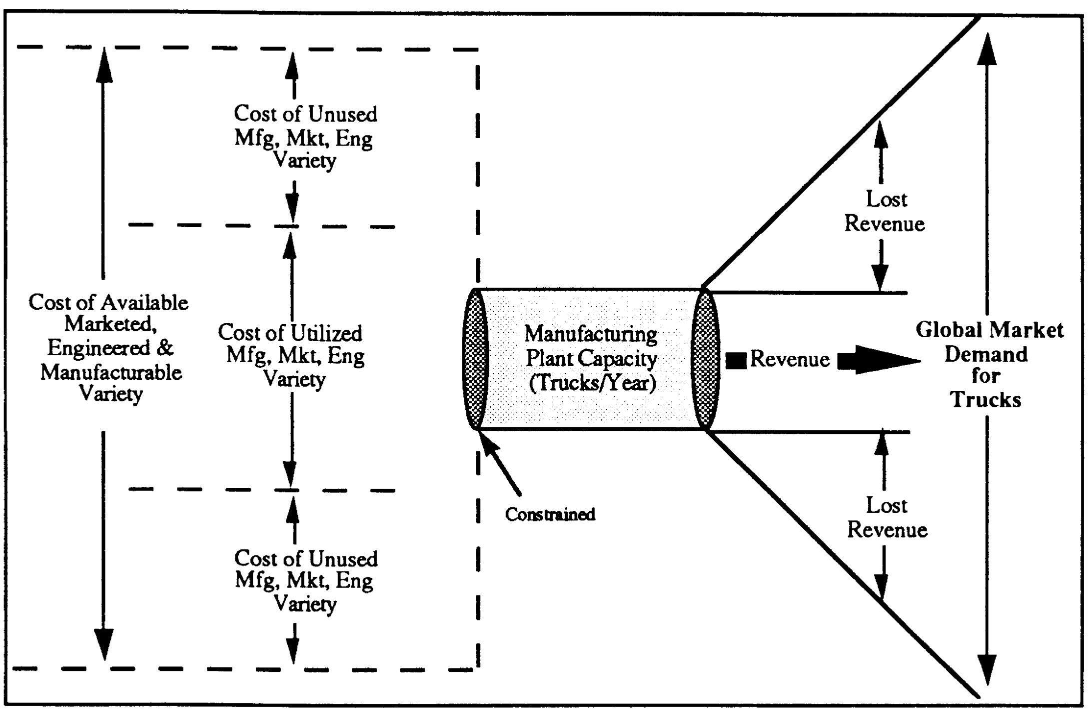



**Figure 1.** Mismatch Between Marketing, Manufacturing, and Distribution Capabilities

### *Goal and Assumption of this Research Project*

The goal of this thesis is not to measure the cost of complexity or the benefits of simplification. Rather, it is to provide a de-proliferation methodology based on perceived customer values and the impact of product features on organizational performance. This thesis assumes that high-level management supports the implementation of such a de-proliferation strategy.

### *Overview of Anticipated Thesis Results*

This study addresses both short- and long-term de-proliferation. In the short term, the focus is on eliminating dysfunctional variety, *i.e.*, product features that are perceived by customers as valueless. The long-term objective is to offer product options that meet customers' desired level of variety but have a low impact on organizational complexity, thereby maximizing profit. A case study of a representative de-proliferation of rear axles on full-size pickup trucks will be referenced throughout.

Figure 2 shows components and parts included in a rear axle assembly. The rear axle de-proliferation effort at North American Truck Platforms eliminated 67 of 131 axles. These deletions accounted for only 4% of the past year's sales. According to market research collected (*e.g.*, GM Powertrain survey of full-size truck customers), most customers will be fully satisfied with another available option. The projected life-cycle savings of de-proliferating rear axles was estimated to be $82 million. Thus, this de-proliferation effort resulted in significant reduction of complexity with minimal impact on customer choice. Figure 3 presents an overview of this thesis, which summarizes seven months of on-site research conducted at General Motors NATP.

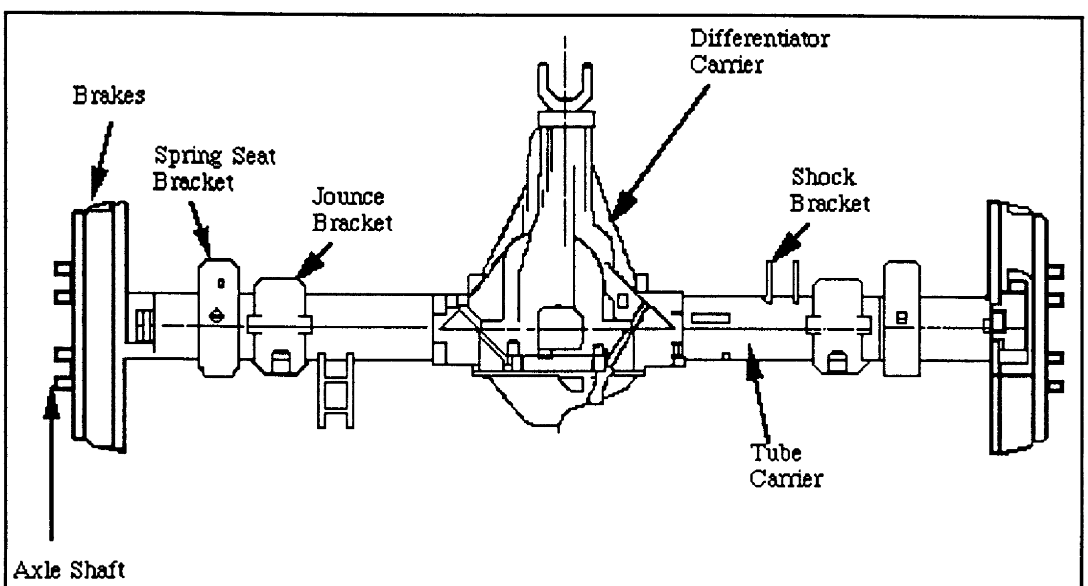



**Figure 2.** Truck Rear Axle Assembly

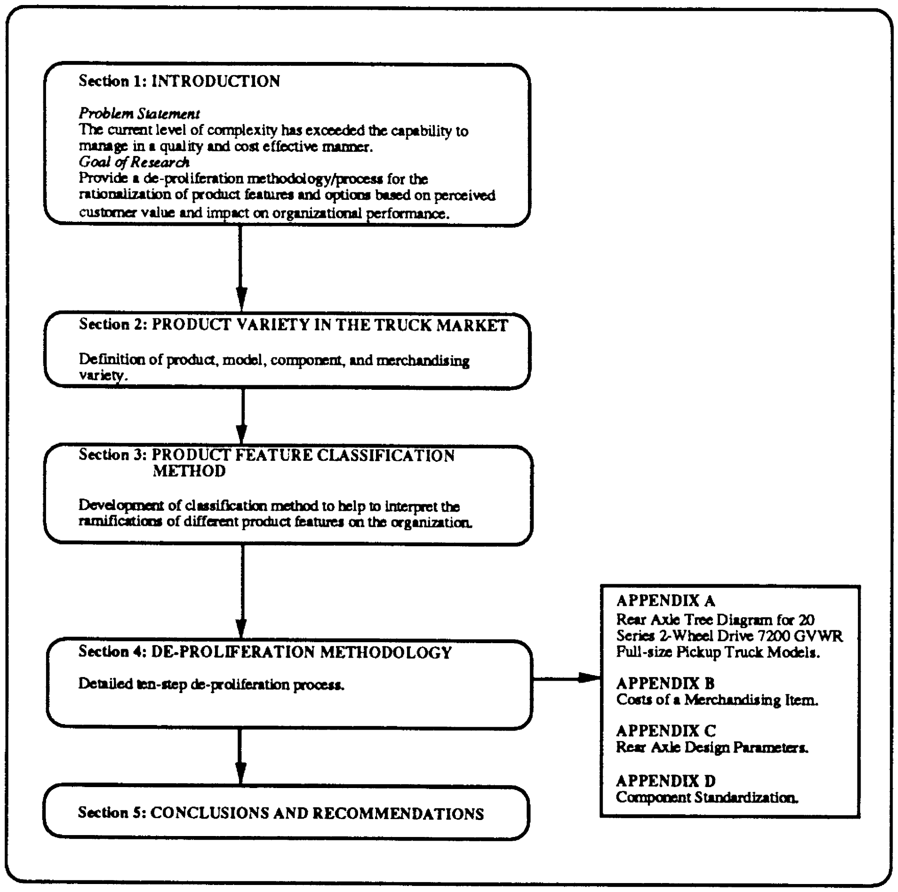



**Figure 3.** An Overview of the Thesis

## *1.2 THE ENVIRONMENT AT NATP*

### *Dramatic Market Growth and Competition*

There are presently four main competitors in the full-size truck market: Chevrolet, GMC, Ford, and Chrysler. Demand for trucks has grown to the point that trucks now represent 40% of the automotive market. At NATP, truck sales have steadily increased by 15-20% annually. Because of this increased demand, all four companies are investing heavily in plant modernization and new product development in order to expand their existing capacities. In reality, all competing products are similar in that they use the box-on-frame architecture. Competitors have therefore differentiated their products through options and merchandising/sales strategies combined with brand image marketing, rather than through basic product differences. Excessive feature proliferation has resulted. Recently there has been an emergence of products (*e.g.*, Ram Truck, and Toyota T-100) that are differentiated by basic product differences (*i.e.*, body styles) combined with brand image marketing, with limited options and merchandising/sales strategies.

### *Customers*

NATP's two main internal customers, Chevrolet and GMC, at times have conflicting needs. In the past as well as today, most of NATP's attention has been focused on Chevrolet because its volume of sales has exceeded GMC's. Although GMC's sales have crept up a few points over the years, they still lagged behind Chevrolet's in 1993 —400,000 units vs. 1,260,000.

The two end-user customers of NATP full-size trucks are fleet (10%), and retail customers (90%). Fleet customers are those that require specialized features (color, engines, axles, etc.) on their trucks. In the past, fleet sales represented a large percentage of trucks sales, but with the expansion of the retail truck market their share has dropped considerably. Retail customers (90%) consists of dealer (70%) and showroom (20%) orders. Dealers, the largest end-user customer for trucks, sell most of their vehicles off the lot from a pre-ordered inventory. This inventory is based on past sales history and varies by region. The showroom buyer is the customer who, because of dissatisfaction with the selection of vehicles available on the lot, chooses to order a custom vehicle directly from the factory.

## 2. PRODUCT VARIETY IN THE AUTOMOTIVE INDUSTRY

Product variety in the auto industry is often categorized as either fundamental (different platforms, models, and body styles) or peripheral (different options). In the truck market, these broad grouping are not sufficient. Instead, four variety types are used: Product, Model, Merchandising/Sales, and Component/Part.

**Product variety (PV)** refers to the distinct basic products offered to the customer (*e.g.*, 1/2-, and 3/4-Ton Pickups, 3/4-Ton Chassis Cab, or Heavy Duty Chassis Cabs).

**Model variety (MV)** refers to the different versions of basic products offered to the customer (*e.g.*, 2-Wheel Drive 1/2-Ton Regular Cab Long-Bed Pickup, 4-Wheel Drive 1/2-Ton Extended Cab Short-Bed Pickup).

**Merchandising/Sales variety (MSV)** refers to distinct standard equipment features, packaged options, and separate (or "free-flow") options offered to the customer (*e.g.*, model variants, which include decor and marketing option packages, body and chassis, power team, wheels and tires, interior options, exterior options, color schemes, standard features). This variety may also include families of components (engines, transmissions, radiators, etc.); packages of options (SLE decor, deluxe front appearance package, etc.); or single free-flow options (bedliner, locking differential, ZFM tires, etc.).

**Component/Part variety (CPV)** refers to the distinct components/parts required to achieve merchandising/sales variety (*e.g.*, shock brackets, jounce brackets, engine mounts, engine cover, pistons, LB4 Engine, Heavy Duty shocks, etc.).

Product, model and merchandising/sales varieties represent what the customer is offered in the marketplace. Component/Part variety, in contrast, is an engineering necessity in producing the customer's choice. The number of possibilities for the different kinds of variety for the full-size pickup are as follows: Product variety, 3; Model variety, 55; Merchandising/Sales variety, 10 trillion; and Component/Part variety, 6500. Figure 4 provides a graphical view of the product hierarchies by variety types. The large number of available merchandising/sales varieties reflects the current marketing strategy of meeting customers' needs through maximum choice. Previous full-size pickup designs had hundreds of millions of MSV item combinations. Product MSV's had grown exponentially to hundreds of trillions of combinations, although recent reductions have decreased them to tens of trillions. Clearly these MSV varieties require further examination; a marketing policy that would dramatically increase MSV's would be to offer new features as free-flow options. Since the de-proliferation of products and model variety lies outside the scope of this thesis, our study will focus on merchandising/sales and component/part varieties.

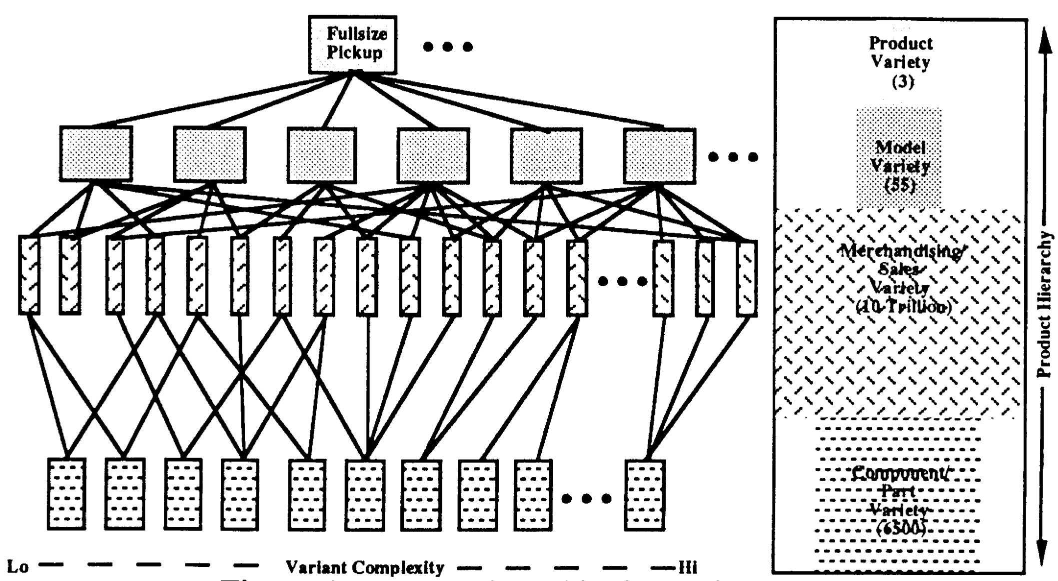



**Figure 4.** Product Hierarchies by Variety Types

## 3. PRODUCT FEATURE CLASSIFICATION METHOD

In the analysis that follows, product features will be classified on the basis of their impact on marketing, engineering, and manufacturing. This classification facilitates the de-proliferation process by providing a common language that crosses all organizational boundaries. These classifications are meant only to be used as indicators to begin to understand how a feature affects organizational effectiveness. Product features will be considered either **integrative** or **nonintegrative**.

**Integrative** merchandising/sales items interact with other vehicle systems and therefore have a major impact on product complexity and variation levels. Being dependent on and integrated with other systems in the vehicle, these items increase the level of coordination needed to successfully design, manufacture, and market them. Further, an item is either "additive," if it increases product complexity by adding items to the manufacturing plant (*e.g.*, ABS brakes, 4-wheel drive); or "substitutive," if by replacing a standard item it increases assembly variability and inventory (*e.g.*, V8 engine, rear axle).

**Non-Integrative** merchandising/sales items do not interact with any other vehicle systems and have an incremental effect on product complexity and variation levels. The distinction between additive and substitutive applies to non-integrative as well as to integrative items.

Figure 5, a 2-by-2 matrix, shows the effects on product complexity and assembly variability of these different classifications.

| | **Non-Integrative** | **Integrative** |
|---|---|---|
| **Substitutive** | Low effect on complexity & variation<br>*e.g.* Steering Wheel Hubcap | High effect on complexity incremental effect on variation<br>*e.g.* 3.42 Rear Axle Radios |
| **Additive** | Low effect on complexity incremental effect on variaiton<br>*e.g.* Bedliners Camper Mirrors | High effect on complexity & variation<br>*e.g.* Two-Tone Paint Locking Differential |

**Figure 5.** Classification 2 by 2 Matrix

As would be expected, Integrative Additive items have the highest impact on the organization and require the most effort to successfully implement. Non-Integrative Substitutive items have the lowest impact on the organization.

A merchandising/sales item is considered either a **differentiator** or a **non-differentiator**.

**Differentiators** increase the variety level by meeting a perceived customer need.

**Non-Differentiators** have no effect on the perceived variety level. Many standard equipment features are non-differentiators. Non-differentiators also include options for which there is little demand (*e.g.*, non-A/C vehicles) as well as those that can easily be purchased as after-market products (*e.g.*, bedliners).

The differentiator vs. non-differentiator distinction reflects the value of a market variant from the customer's point of view. Over time, evolving customer expectations can transform items from differentiators (*i.e.*, customer exciters) into non-differentiators (*i.e.*, standard equipment). For this reason, the organization needs to eliminate less-than-optimal MSV's to make room for newer product features.

# 4. DE-PROLIFERATION METHODOLOGY

### *Overview*

The de-proliferation process proposed in this study consists of ten steps, as depicted in Figure 6. The process initially identifies de-proliferation candidates and then analyzes and ranks them on the basis of sales data, customer feedback, and a life-cycle cost assessment. [The term candidate will be used throughout this discussion to signify an element that might be considered for elimination.] The first stage of de-proliferation is a "housecleaning" of dysfunctional variety not valued by the customer. The second stage seeks to implement systemic changes by focusing on drivers of product proliferation to prevent unnecessary future market defects. This stage addresses the reduction of component/part variety through standardization, as well as the alignment of marketing and manufacturing strategies.

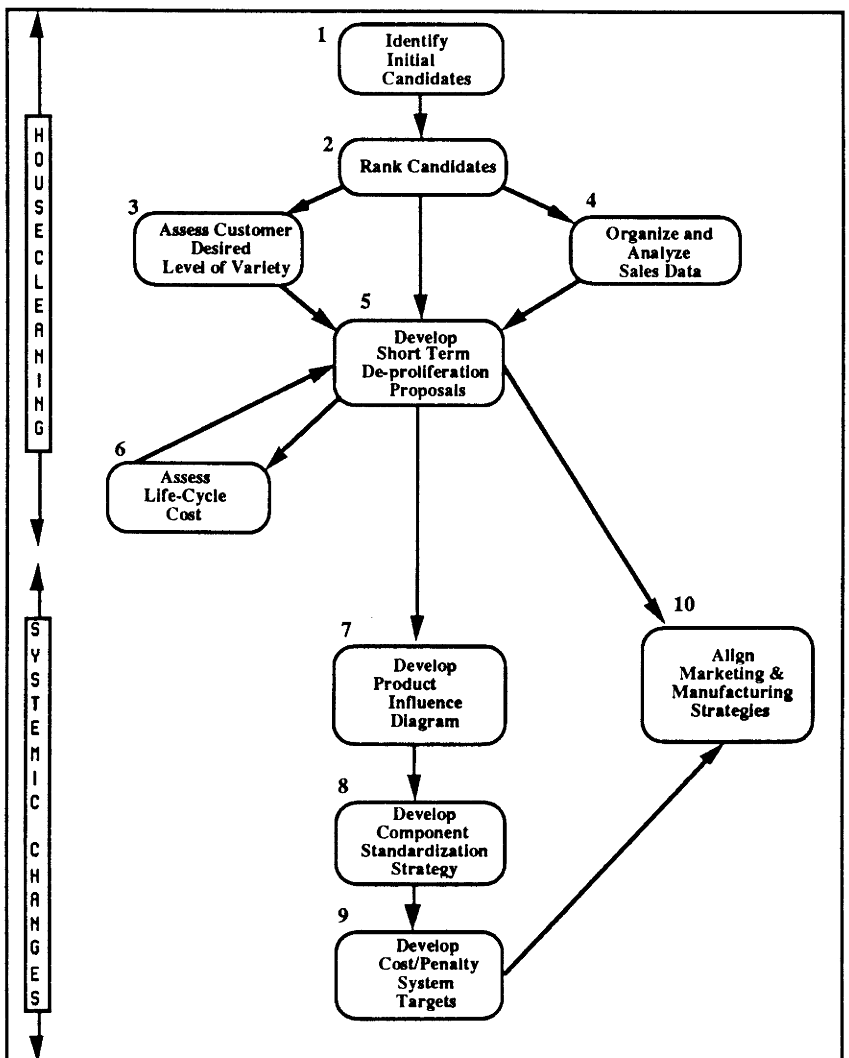



**Figure 6.** Flowchart of De-Proliferation Process

### *4.1 IDENTIFY CANDIDATES FOR DE-PROLIFERATION*

The first step in de-proliferation is to identify items that would be good "candidates" for elimination. Prime candidates for de-proliferation include the following:

- Non-package ("free-flow") options for which customer demand is low.
- High-demand options that can be shifted to base content.
- Options available both in packages and separately.
- Features that are different for GMC and Chevrolet Trucks.
- MSV's that customers perceive as having no value.
- Low volume (*i.e.*, <1000/year—truck models).

Additional candidates should be solicited from the marketing, engineering, planning and manufacturing groups, who should use such readily available tools as marketing studies, engineering studies, order guides, quality audits, and warranty data. The focus should be on identifying candidates whose elimination or optimization would (a) improve quality, (b) reduce operating and engineering system costs, (c) simplify ordering scheduling, and (d) improve customer satisfaction. Examples of such candidates are rear axles, exterior colors, Marketing Option Package 1SL, SL Decor, long bed, GVW rating, Snow Plow Prep Package, and radiators.

### *4.2 RANK INITIAL CANDIDATES*

The candidates thus identified should then be ranked by a number of staff members representing different functions. A weighted classification point system that can be used for this ranking is described in this section. This system characterizes each feature or option according to attribute dichotomies discussed previously:

substitutive / additive,
integrative / non-integrative, and
differentiating / non-differentiating.

Points are assigned for each characteristic, as shown in Table A. The resultant total "DePro" (de-proliferation) score reflects the impact the item has on the complexity of the organization. A higher score implies that this feature/option has a greater impact on organizational complexity. Table A shows examples of this weighted classification method. The weights assigned to the classifications are based on objective observations of their impact on complexity. The initial results yielded by this system should be tabulated and the results redistributed through the organization for review. A series of meetings should be arranged to determine the top candidates for de-proliferation. Obtaining support for this effort from the key players in the organization will ensure that the findings of the de-proliferation process are taken seriously.

| Feature/Option | Substitutive (1) or Additive (2) | Integrative (4) or Non-Integrative (0) | Differentiating (0) or Non-Differentiating (4) | DePro Score |
|---|---|---|---|---|
| 3.42 Ratio Rear Axle | 1 | 4 | 4 | 9 |
| Aluminum Wheels | 1 | 0 | 0 | 1 |
| Bedliners | 2 | 0 | 4 | 6 |
| Two-Tone Paint | 2 | 4 | 0 | 6 |
| Leather Steering Wheel | 1 | 0 | 0 | 1 |
| AM Radio | 1 | 4 | 4 | 9 |
| Glovebox Insert | 1 | 0 | 4 | 5 |
| 3.08 Ratio Rear Axle with Locking Differential | 2 | 4 | 4 | 10 |

**Table A.** De-Proliferation Candidate Ranking Scheme

### *4.3 ASSESSING THE CUSTOMER'S DESIRED LEVEL OF VARIETY*

Assessing the value of merchandising/sales variety from a customer perspective is the key to properly rationalizing a product line. If not valued by the customer, the variety offered is merely a market defect. Variety is helpful only when it meets the needs of the customer. The control of marketing costs and sales prices begins even before the car leaves the computer screen. By ensuring that a design satisfies the needs and desires of the customers in terms of size, features, performance, and so on, a manufacturer can sell a new automobile for a higher price and avoid expensive rebates or other merchandising/sales inducements. In the next wave of proliferation, customer demand will drive merchandising/sales varieties.

Marketing must de-proliferate non-essential, non-value-added offerings that are a deterrent to buying. A fair assessment of a merchandising/sales item's value to the customer can be made by a multidisciplined team in meetings with the customer. Five key factors determine the marketing value of an MSV item to the customer and the organization: (a) variety strategy, (b) variety value, (c) buying experience, (d) organizational balance, and (e) organizational impact. In discussing these factors, we will refer to rear axles to illustrate each one.

### *Variety Strategy*

Variety strategy refers to how the merchandising/sales item is merchandised to the customer. Is it standard equipment, a packaged option, or a free-flow option? Does the customer feel he has enough choices? Does he understand the functionality of the product?

#### *Variety Strategy for Rear Axles*

Rear axles are merchandised by axle ratio (3.08, 3.42, 3.73, etc.), model series (10, 20, 30 series), and free-flow options (*i.e.*, locking differential, auxiliary springs, Gross Vehicle Weight Rating (GVWR)). During an axle de-proliferation effort carried out recently, those involved were astonished at the small number of dealers who had a good understanding of how different axle ratios and the locking differential feature affect vehicle performance.

### *Variety Value*

Variety value refers to how the customer perceives the merchandising/sales item. Does a product feature have a perceived value to the customer? Is the customer completely satisfied with the item? Is the item an "exciter" or a "must-have" feature?

#### *Variety Value of Rear Axles*

In a GM Powertrain survey of full-size truck customers, about half of the respondents did not know what axle ratio they had. In fact, of those who thought they knew, about half checked the wrong ratio. Most customers felt more comfortable speaking about fuel economy and performance than about axle ratios.

### *Buying Experience*

It is important to know how the customer perceives the buying experience, which must be simplified to increase buyer satisfaction. Situations in which the customer is asked to "engineer" the vehicle, with resultant confusion and error, should be identified. Does the order guide present the buyer's choices in a consistent and clear manner?

*Buying Experience of Rear Axles*

Many dealers have complained of difficulty in ordering rear axles for full-size pickup trucks because of order complexity. The ordering process has resulted in mistakes that reduced the responsiveness of the system and led to customer dissatisfaction. The order guide complexity results from use of a single volume to include all model variants needed to support the fleet, and retail customer. The main reason given for why separate order guides could not be produced for each customer type was cost.

### *Organizational Balance*

Organizational balance refers to harmony between manufacturing and distribution capabilities. Do existing manufacturing capabilities support the marketing strategy for an item? What warranty and quality problems are associated with the item? Does the distribution channel provide the customer with the available range of manufacturable variety?

*Organizational Balance due to Rear Axles*

Currently the manufacturing organization is experiencing many problems with rear axle manufacturing and assembly. Warranty and inventory cost at the assembly plant are high. The inability of the distribution channel to offer the customer the available range of manufacturable variety translates into a market defect.

### *Organizational Impact*

Organizational impact refers to the effect of the merchandising/sales item on the entire organization. The impact of a MSV item on the organization (*i.e.*, additive, integrative, non-differentiating) must be weighed against its value to the customer. The possibility of making popular items independent modular options should be explored.

*Organizational Impact of Rear Axles*

The axle de-proliferation effort proposed the elimination of 67 rear axles, or 51 % of the current full-size axle offerings. Analyzing the associated manufacturing costs — labor, rework, quality issues, freight charges, and inventory storage — the team estimated savings of about $6.5 million per year. Associated savings in engineering yield another $17 million, giving total savings over a ten-year period of roughly $82 million.

***Summary***

The assessment of the five factors discussed above should identify what is important to the customer and suggest areas of opportunity for de-proliferation. The goal is to merchandise items so as to minimize ordering complexity and improve the buying experience and customer satisfaction while at the same time reducing organizational complexity. Table B illustrates a partial summary of de-proliferation opportunities based on the assessment of customers' desired level of variety for full-size pickup rear axles.

**Merchandising/Sales Item : Full-Size Pickup Truck Rear Axles**

**Importance to Customer**

Retail Buyers: Price/Fuel Economy and Trailering/Performance
Fleet Buyers: Axle Set and Price/Fuel Economy

**Opportunities**

1) Eliminate locking differential and auxiliary springs as free-flow options. Package locking differential with higher axle ratios (3.73), as competitors are doing. These changes will avoid having customers engineer their vehicles and thereby eliminate the resulting confusion and less-than-optimal engine/transmission/axle combinations.

2) Cease to market rear axles by axle ratios, axle set, and options for retail customers. Market rear axles in customer terms: Price/Fuel Economy Leader and Trailering/Performance Leader.

3) As a result of (2) above, reduce the number of axle sets per model to two.

4) Cease to offer semi-floating rear axles for 8600 GVWR rating models. The customer perceives that 8600 GVWR models should utilize heavy duty full-floating axles.

5) Have engineering recommend optimal engine/transmission/axle combination packages to reduce market defects and improve the Corporate Average Fuel Economy (CAFE) forecast.

6) Create separate order guides for fleet and retail customers.

etc. ........ Page 1 of 4

**Table B.** Partial Summary of De-proliferation Opportunities Suggested by Assessment of Customers' Desired Level of Variety for Full-size Pickup Truck Rear Axles

### *4.4 ORGANIZING AND ANALYZING SALES DATA*

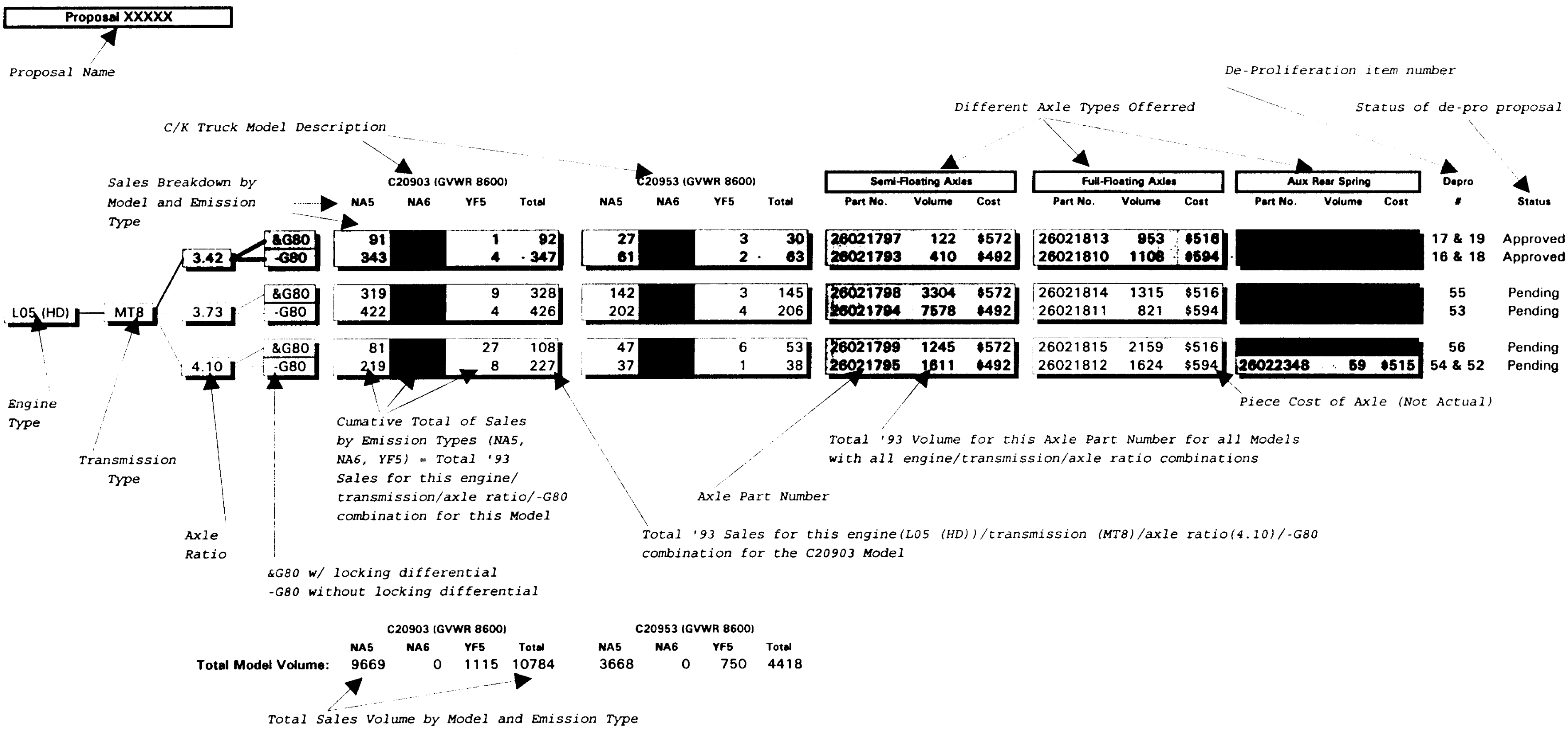
In order to assess the popularity of merchandising/sales items it is important to thoroughly analyze sales data for the most recent year both at a model level (*i.e.*, 1/2-, and 3/4-Ton-series trucks), and within each model.

Sales data should be presented in a manner that reflects the level of variety offered to the customer at a model level, grouping models that share a specific merchandising/sales item. A tree diagram (Figure 7) is an ideal way to present the sales data delineated by truck model type, usage, product family, and marketing sector. Information must include all pertinent information needed by marketing, engineering, planning, and manufacturing personnel to make decisions. Personnel from these areas should be asked to identify the information required to determine the viability of de-proliferation of each merchandising/sales item. Table C shows the list of information that manufacturing, engineering, and marketing personnel requested for the rear axle de-proliferation decision meeting.

| Description of Information | Requested by |
|---|---|
| 1) Cumulative Rear Axle Sales by Model Type | Marketing, Manufacturing and Engineering |
| 2) Rear Axle Sales by Axle Part Number | Manufacturing |
| 3) Rear Axle Sales by Engine and Transmission Type | Engineering |
| 4) Rear Axle Sales by Emission | Engineering |
| 5) Rear Axle Sales by Axle Type, and Axle Ratio | Marketing, Manufacturing and Engineering |
| 6) Rear Axle Sales Differentiated by G80 (Locking Differential) Free-flow Options | Marketing and Manufacturing |

**Table C.** Information Requested for Rear Axle De-proliferation

Appendix A provides a complete set of tree diagrams for the 20 Series 2-Wheel Drive 7200 GVWR full-size truck models, utilized for the rear axle de-proliferation. The tree diagrams provided the basis for constructive conversations among the members of the product development team, allowing them to integrate the data with their personal knowledge in making recommendations on how to de-proliferate rear axles.




**Legend**

Black shading indicates this engine/transmission/axle ratio combination is not offerred for this model

Light dots shading indicates this engine/transmission/axle ratio combination was de-proliferated for the 1994 MY

Dark Grey Shading indicates this engine/transmission/axle ratio combination is a recommended de-proliferation item

| | |
|---|---|
| NA5 | Standard Emission |
| YF5 | California Emission |
| NA6 | High Altitude Emission |
| LB4 | V6 4.3L EFI Engine |
| LB4(HD) | V6 4.3L Heavy Duty Engine |
| L03 | V8 5.0L Engine |
| L05 | V8 5.7L Engine |
| L05 (HD) | V8 5.7L Heavy Duty Engine |
| L19 | V8 7.4L EFI Engine |
| LH6 | V8 Diesel 6.2L NA |

| | |
|---|---|
| L65 | V8 Heavy Duty Diesel 6.5L |
| L49 | V8 Diesel LD Nat Asp 6.5L |
| LL4 | V8 Diesel 6.2L Nat Asp |
| MXO | Automatic Transmission |
| MT8 | Manual 5-Speed w/ Deep Low |
| MG5 | Manual 5-Speed (Getrag) |
| &G80 | With locking differential |
| -G80 | Without locking differential |



**Figure 7: Full-Size Truck Rear Axle Tree Diagram**

### *4.5 DEVELOPING SHORT TERM DE-PROLIFERATION PROPOSAL*

At this point a de-proliferation proposal incorporating the findings of the previous steps can be drafted. Such a proposal should be simple and concise. It should describe recommended de-proliferation by model, volume affected, number of merchandising/sales items eliminated and remaining, rationale for de-proliferation, and benchmarking of competitors' equivalent offerings.

### *4.6 LIFE-CYCLE COST IMPACT OF DE-PROLIFERATION*

To support the de-proliferation proposal, a financial analysis of the potential cost savings should be completed. Knowledge of the future life-cycle cost impact of de-proliferating merchandising/sales items may well accelerate the implementation of the recommendations. Additionally, the total potential savings can be used to gauge the success of de-proliferation.

Proforma, a simple cost-estimation tool, is suggested for assessing the life-cycle cost of complexity of a merchandising/sales item. The proforma format provides a quick and effective method of quantifying the short- and long-term impact of an item on the organization and also yields a rough estimate of the cost of marketing, engineering, and manufacturing the item.

The costs of an existing merchandising/sales item are assumed to include two factors:

- Direct incremental costs of design, production, assembly, and set-up;
- Environmental costs of the added complexity.

Direct incremental costs are those required to support the items; *e.g.*, labor hours, utilities, tooling. Environmental costs are those incurred because of the system effects created by the increased complexity; *e.g.*, idle time, line balancing, quality problems. A list of the types of incremental costs are provided in Appendix B: Table D. Appendix B: Table E lists some of the associated environmental costs.

Because of the traditional cost accounting that is currently utilized at NATP, it is difficult to assess the cost for individual items since it is accounted for at an aggregate level. Estimations based on expert advice provide approximate costs of individual items. The proforma analysis should consist of four sections: manufacturing costs, those related to quality, assembly, labor, distribution, and logistics; engineering costs, those involved with the design and tooling related to the item; marketing costs, those associated with advertising and marketing the merchandising/sales item; and a summary of the projected life-cycle savings of the de-proliferation proposal. "Life-cycle" refers to the product's life in the market, which for full-size pickups has been about ten years. Figure 8, 9, and 10 provide examples of typical proforma analyses that were completed for the rear axle de-proliferation proposal. In that case a marketing proforma cost sheet was not created because marketing costs proved to be too aggregate.

Figure 8 tabulates the associated costs of designing and engineering a new axle set (8.5", 9.5"). The analysis includes realistic but conservative estimates of testing, validating, tooling, and support costs associated with the introduction of a new axle set. The percentage reduction in costs was based on expert knowledge of the de-proliferation candidate's impact on the these factors. For example, tooling costs are reduced only 10%, reflecting that they decrease dramatically only when an entire axle set (8.5", 9.5", 10.5") is eliminated.

Figure 9 outlines the manufacturing cost of assembling and installing rear axles. It shows that manufacturing cost includes labor, floor space, plant inventory, re-work, and scrap. De-proliferation is projected to reduce annual operating costs by $6.5 million per year. Figure 10 summaries the life-cycle savings of de-proliferation, which in the case of rear axles works out to about $82 million.

Though only one factor in the decision-making process, the potential savings derived from the proforma analysis can add a great deal of credibility to de-proliferation. A tangible monetary goal—$1 billion for '95MY—would accelerate the de-proliferation process and allow the organization to drastically reduce the level of complexity—and thereby increase productivity.

| | % Reduction in Engineering Cost after 50 % Depro | New Life-Cycle Cost after Depro |
|---|---|---|
| Design Cost per Axle Set | 30% | |
| Testing & Material Cost per Axle Set | 30% | |
| Validation of Axle Set in C/K Model | 30% | |
| Tooling Costs per Axle Set | 10% | |
| Current Product Engineering Support | 50% | |
| Total Cost to Develop an Axle Set for C/K Product | | $35,773,000 |
| Current Number of Axle Sets in C/K lineup (8.5", 9.5", and 10.5") | | 3 |
| **Total Life-Cycle Cost of Axle Engineering for C/K Program** | | $107,319,000 |
| **Total Life-Cycle Engineering Potential Cost Savings** | | $16,851,000 |

**Figure 8: ProForma Analysis of Life-Cycle Cost of Axle Engineering and Design for Full-Size Pickup Trucks.**

| | % Reduction In Operating Cost after 50 % Depro | Yearly Operating Cost after Depro |
|---|---|---|
| **Quality Costs** | | |
| Misidentified Axles at Assembly Plant | 70% | |
| Misidentified Axles at Supplier Plant | 70% | |
| Other Axle Problems Detected at Assembly Plant Resulting in Scrapping Axles | 20% | |
| Other Axle Problems Detected at Assembly Plant Needing Repair | 20% | |
| Premium Freight Charges for Delivery of Low Runners | 80% | |
| Material Handling Personnel at Plants | 30% | |
| Carrying Cost of Plant Inventory of Axles | 60% | |
| Plant Floor Space | 40% | |
| C/K Assembly Labor | 10% | |
| **Total Axle-Related Operating Cost per Year for All Four C/K Plants** | | $24,918,800 |
| **Average Axle-Related Operating Cost per Plant** | | $6,229,700 |
| **Projected Annual Savings per Plant due to De-proliferation** | | $1,638,300 |
| **Total Projected Annual Savings for All Plants due to De-proliferation** | | $6,553,200 |
| **Total Axle-Related Life-Cycle Operating Cost Savings (10 years)** | | **$65,532,000** |

**Figure 9: ProForma Analysis of Yearly Axle Related Operating Costs for Assembly Plants**

| Projected Savings due to De-Proliferation | |
|---|---|
| Total Life-Cycle Engineering Potential Cost Savings | $16,851,000 |
| Total Axle-Related Life-Cycle Operating Cost Savings (10 years) | $65,532,000 |
| Projected Total Life-Cycle Savings of De-proliferation Proposal | $82,383,000 |

**Figure 10: Proforma Analysis of Total Life-Cycle Savings of Axle De-proliferation Proposal**

## *4.7 PRODUCT PROLIFERATION INFLUENCE DIAGRAM*

The complexity of interrelations among the various elements associated with a product can best be portrayed graphically by an influence diagram, of which Figure 11 is an example. Such a diagram should identify (a) key drivers of proliferation and the costs of complexity in logistics, purchasing, production, and marketing; (b) each part/component (Figure 3) and key design and manufacturing parameter of a product; (c) the key customer-driven design parameters that may be modularized; and (d) those internally driven factors which may be standardized.

The key design parameters should be shown in terms of their relation to the parts/components they interact with. While the key design parameters should describe the design criteria that define the parts/components or features that make up a product, the key manufacturing parameters should describe those that have the greatest impact on plant operations. Appendix C: Table F shows the list of parts and key design and manufacturing parameters that were identified for the rear axle project.

The resulting influence diagram should describe the relationships among the parts/components and their key design and manufacturing parameters. These interconnections will promote an understanding of the interactions that occur in the product.

The product proliferation influence diagram in Figure 11 describes the interactions that exist for the rear axle. Additionally, the key design features driven by the customer directly, shaded in the diagram, were identified to be Load/GVWR, Tube OD/ID 2- and 4- Wheel Drive, Single or Dual Wheel Rear Axle, and Axle Sets/Ratios. The other design parameters, represented by unshaded rectangles, are internally driven by engineering and marketing specifications. From this diagram one should be able to understand the critical factors that cause the proliferation of a product and to see opportunities for standardizing valueless components/parts. These diagrams help show marketing, engineering, and manufacturing personnel what factors influence their ability to maintain cost competitiveness and to reduce manufacturing and engineering complexity while also maintaining an appropriate level of model variety to satisfy the customer.

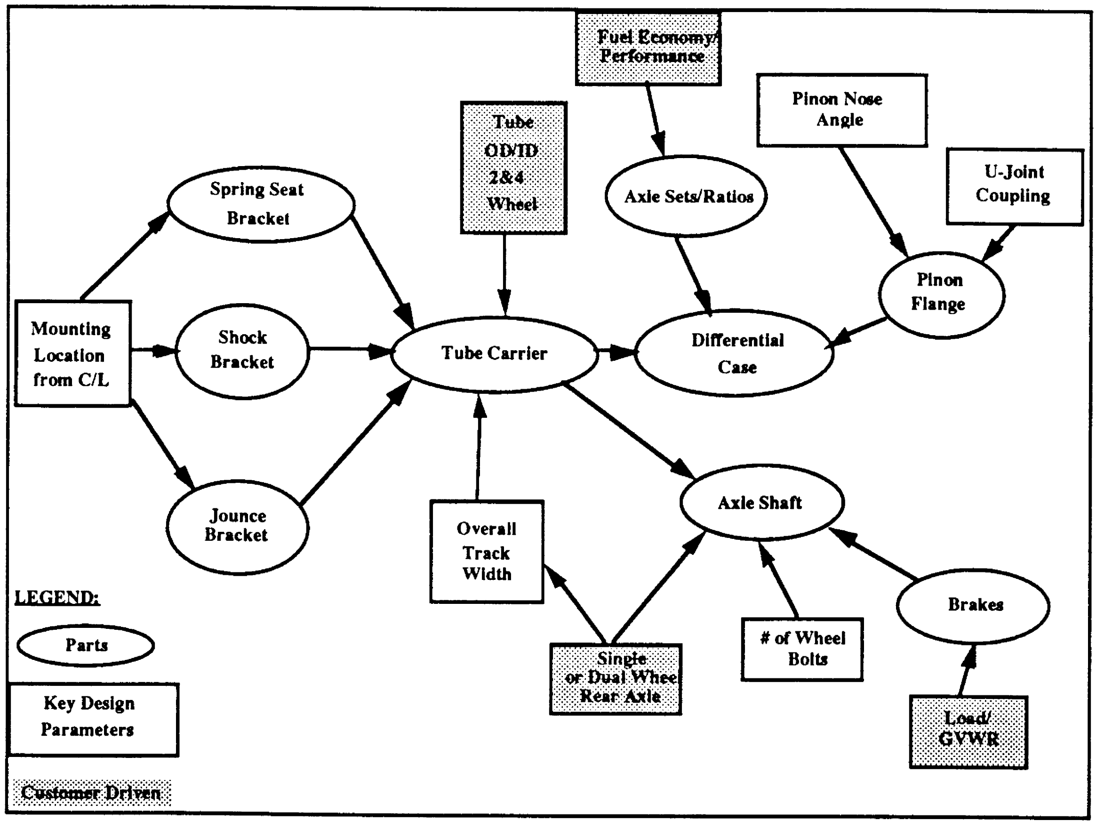



**Figure 11.** Rear Axle Proliferation Influence Diagram

Through a combination of process flexibility, modular design, and component standardization high model variety can be achieved without high component variety. In fact, the proper investment in process flexibility, modular design, component standardization, worker skills, and operations management can dramatically reduce the cost of component variety. Therefore, the next logical step in de-proliferation analysis is to identify opportunities for component standardization.

## *4.8 COMPONENT STANDARDIZATION STRATEGY*

Standardizing components across models can significantly reduce the cost of manufacturing automotive components while increasing the ability to offer model variety without any major cost penalty. The de-proliferation of components can also have a major impact on reducing build-complexity costs. The standardization of non-differentiating components can be viewed both as de-proliferation of components that make up a product and as part of the ongoing strategy to achieve component uniformity within NATP.

The same group that implements a short-term de-proliferation can help to shape a long-term de-proliferation for new product program teams. The algorithm suggested to assess the opportunities for component standardization is:

1) Count the number of different existing component variations for a particular product line. Figures 15, 16, and 17 of Appendix D pictorially show, respectively, variant shock brackets, axle tubes, and axle shafts currently in production for the full-size truck.

2) Examine the component variation charts to discover why this component proliferation occurred and to determine an optimal level of variety for future products.

3) Assess the competition's components and assembly efficiency to determine what level of standardization should be achieved.

4) Begin to develop a "Leapfrog Design and Manufacturing" template (Figure 12) by proposing an optimal design based on key customer-driven design parameters and the minimal number of components/parts needed to meet the internally-driven key design parameters. Be creative and look for valueless components that simply proliferate the product. These templates should identify the optimal component/part count and corresponding key design parameters required to achieve world-class components. The "Leapfrog Design and Manufacturing" template should not be developed in isolation but rather by a multidisciplined team including outside members (*i.e.*, suppliers) as needed. For the rear-axle study a strong multifunctional team included representatives from marketing, manufacturing, engineering, planning, and the supplier. This multifunctional team was able to accomplish this task in half the time and helped to set the goals for the next product development program. The design and manufacturing template (Figure 12) was drafted to describe the next logical step in the de-proliferation of this product feature. Starting with customer-driven design parameters (Load/GVWR, Tube OD/ID, 2- and 4-Wheel Drive, Fuel Economy/Performance, and Single or Dual Wheel Rear Axle) the team determined a need for 2 brake assemblies to meet customers' Load/GVWR requirements; 2 tube assemblies to meet 2- and 4-Wheel Drive customer design preferences; 2 axle sets/ratios to satisfy customers' desire for Fuel Economy or Performance; and 2 additional Tube Assemblies to meet Single or Dual Rear Wheel design preferences. The minimal number of components needed to address all the internally driven design parameters were then determined. Finally, manufacturing enablers were identified on the basis of the manufacturing equipment's flexibility.

| Parts | Part Count | Key Design Parameters |
|---|---|---|
| Univeral Spring Seat Bracket | 1 | Mounting location from centerline |
| Universal Jounce Bracket | 1 | Mounting location from centerline |
| Universal Shock Bracket | 1 | Mounting location from centerline |
| Universal Tube Assembly | 4 | 2- and 4-Wheel Dr. (2), and track width (2) |
| Differential Carrier | 1 | Tube OD |
| Pinon Flange | 1 | U-Joint coupling |
| Brakes (JB7, JB8) | 2 | Load/GVWR |
| Axle Shaft | 4 | Wheel Bolts, tube length, and brakes |
| Axle Sets/Ratios | 2 | Fuel Economy/ Performance |
| Wheel Hub | 2 | 1 for single wheel rear, and 1 for dual wheel rear. |
| MFG Enablers | | |
| • Common pinon nose angle (one size) | | |
| • Package locking differential option (G80) with higher axle ratios rather then as a free-flow option | | |

**Figure 12.** "Leapfrog Design and Manufacturing" Template for 10.5" Two and Four Wheel Drive Rear Axles

These simple templates establish an approved build of materials for low value components and simple guidelines for product designers. Additionally they should help to establish targets for future product program management. These templates will ensure that the initial de-proliferation efforts are not wasted and that the organization does not revert to its previous mode of operation. Market changes may require revising these targets but hopefully the information provided will permit increasing product variety without greatly affecting the cost of complexity.

## *4.9 CREDIT/PENALTY COST SYSTEM*

Once the component standardization strategy is implemented, the next system needed is one to ensure that the de-proliferation effort is effective long-term. This can be achieved by changing the cost system for new vehicle programs to apply cost credits or penalties, based on part number levels, to preserve the gains of de-proliferation. Figure 13 illustrates this cost system. The zero base (N) would be set by the supplier and program team during phase one of the product development process. The product program would then incur a piece-cost penalty, determined as a percentage of cost, for every increment (*i.e.*, N+1) of proliferation over the established zero base. This penalty would consist of a labor/burden paid to the manufacturer and a flexibility penalty paid to the assembly plant to accommodate the resultant increase in variety. The platform would enjoy a piece-cost savings from the supplier in the event that fewer parts than the zero base were required. This cost system would drive program managers to continuously trade off non-value added variety with cost.

| | # of Part Numbers per package | Labor/Burden ------ Credits/Penalties | Flexibility ------- | Total |
|---|---|---|---|---|
| | N-9 | -7% | 0% | -7% |
| | N-7 | -6% | 0% | -6% |
| | N-6 | -5% | 0% | -5% |
| CREDITS ===> | N-5 | -4% | 0% | -4% |
| | N-3 | -3% | 0% | -3% |
| | N-2 | -2% | 0% | -2% |
| | N-1 | -1% | 0% | -1% |
| ZERO BASE ===> | N | 0% | 0% | 0% |
| | N+1 | 1% | 1% | 2% |
| | N+3 | 2% | 2% | 4% |
| PENALTIES ===> | N+5 | 3% | 3% | 6% |
| | N+7 | 4% | 4% | 8% |
| | N+10 | 5% | 5% | 10% |
| | N+14 | 6% | 6% | 12% |
| | N+17 | 7% | 7% | 14% |

**Figure 13.** Credit/Penalty Cost System

In the case of rear axles, the zero base would be approximately 64 axles, since 67 of 131 axles offered were de-proliferated. The product team would incur a piece-cost penalty for every axle offered to the customer over the zero base (*e.g.*, 65 = 2 % piece-cost penalty, 74 = 10 %) or a piece-cost credit for every axle variant that was removed from the zero base (*e.g.*, 63 = -1 % piece-cost credit, 58 = -5 %).

### *4.10 MANUFACTURING AND MARKETING STRATEGIES*

The de-proliferation effort should help to align manufacturing and marketing strategies by de-emphasizing weaknesses and building on strengths. Functional interactions have an enormous importance in the quality of strategic decision making. Because of the existing managerial styles at NATP there is excessive specialization of managers. The ability of the key managers in marketing and manufacturing to work as a team with a much clearer integrative capability would ensure congruent and effective manufacturing and marketing strategies.

There are two central issues in developing congruent and effective functional strategies. The first is identifying the key decision-making categories that are linked to each major function and that pinpoint the sources of competitive advantage at the functional level. The second issue is measuring functional performance, *i.e.*, opportunities to achieve competitive advantage.

The key decision-making categories that link manufacturing and marketing are product strategy, new product development and introduction, distribution, and pricing. The difficulty of manufacturing is influenced by the range of products and processes, volume forecasts, product differentiation, and the rate of new product introduction. Manufacturing and marketing must cooperate to make decisions about product scope and new products. For example, if marketing desires rapid and frequent product introductions, then manufacturing must design flexible, responsive, efficient plants. Design, marketing, and manufacturing must communicate effectively to prevent excessive diversification and lack of focus in the products manufactured in a given plant.

A general-purpose process to guide managers in formulating a manufacturing-marketing strategy is

1) Develop a framework for strategic decision making.
2) Assure that marketing strategies and manufacturing strategy are linked.
3) Conduct an initial manufacturing strategic audit to determine strengths and weaknesses in the current manufacturing organization. Utilize competitive benchmarks from companies inside and outside of the automotive industry (*e.g.*, GM can learn from Kodak, as well as Ford), to make these assessments.
4) Determine the customers' desired level of variety and the level of variety currently offered.
5) Examine the degree to which the manufacturing strategy complements the marketing strategy. Examine the degree of product complexity that exist at each plant.
6) Develop manufacturing and marketing strategies that result in competitive advantages.

## 5. CONCLUSIONS AND RECOMMENDATIONS

*Conclusions*

- An organization's ability to balance its capabilities against the range and variety of its products can dramatically affect its costs.

- A manufacturer can achieve a high perceived variety level by developing product specifications and service standards that meet customer needs more closely than those of its competitors.

- A pragmatic approach to developing a perceived variety level can help reduce the level of product complexity in the organization while maximizing profit.

- The convention that more variety is better is deceptive. Profit and cost must be understood by those who choose appropriate variety levels (Figure 14).

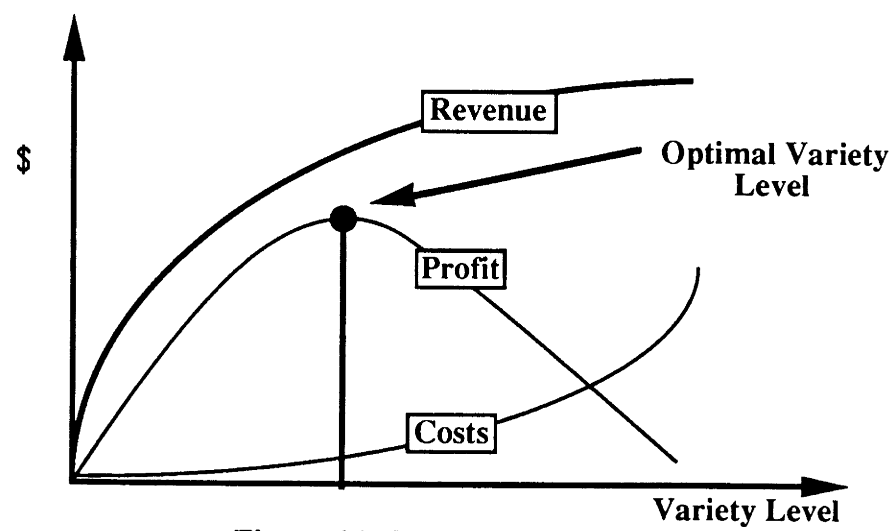



**Figure 14.** Optimal Variety Level

- The impact of product features on the organization depends upon their characteristics.

- The mismatch among manufacturing, marketing, and distribution capabilities suggests that functional strategies are poorly coordinated.

- Current NATP business systems and marketing practices should focus on regional and lifestyle variations rather than on the requirements of individual customers. This may be achieved by differentiating products by basic product differences (*i.e.*, body styles) combined with brand image marketing, with limited options and merchandising/sales strategies.

- The costs of variety may be lessened by proper investment in process flexibility, modular design, component standardization, worker skills, and operational management.

- An effective de-proliferation effort can dramatically reduce an organization's complexity level with little or no impact on customer choice.

- De-proliferation principles are general rules that can be applied to all products and processes in the organization. The following principles encapsulate how product features or options can be successfully de-proliferated:

1) De-proliferation must "go all the way"; that is, the feature or option to be de-proliferated must be eliminated from all models.
2) Not all build combinations are created equal. Some features have a greater number of interactions with other vehicle systems, which requires extensive coordination. For example, a hubcap option has less of an effect on the organization's performance than a new engine offering.
3) Customers should not be asked to order features that require extensive engineering knowledge. For example, the rear axle section of the order guide should be phrased in terms of customer needs, which would then dictate the optimal specification (*i.e.*, axle ratio, or locking differential ).
4) Variety in and of itself is not customization. Features that have no perceived value to the customer do not truly serve the customer.
5) Complexity is a commodity. Management must proactively confront the effects of complexity on the organization by aggressively de-proliferating valueless content.
6) Strategic alliances must be used to increase variety. An example of this type of alliance is the recent transition of bedliner installation from the assembly plant to the dealer which has reduced the burden on the organization while improving it's responsiveness to customer needs.

7) Special Equipment Orders (SEO) should be separated from mainstream operations. A separation of retail and fleet order guides will reduce the level of confusion in ordering new vehicles.
8) The negative effects of variety can be damped by designing popular features (*i.e.*, air conditioning), in a modular fashion, thereby reducing their need for interaction with other vehicle systems.
9) The organization must ensure that its complexity threshold is not exceeded by balancing the level of variety offered with the organization's capabilities. Management must fully understand the impact of adding new variety on the total organization; the optimization of variety level would be the point where marketing needs are closely matched with manufacturing capacity.
10) Dysfunctional variety should be eliminated before more difficult organizational changes are tackled.

***Recommendations***

Outlined below are recommendations that should help NATP improve its ability to cope with complexity and implement a de-proliferation process throughout the corporation.

• Consolidate the order guide and vehicle description system (VDS) into one system, for example by adding a merchandising/sales field to the VDS and automatically generating order guides from it. At present a great deal of time is spent addressing which items are merchandised and which have been engineered for a particular product lineup, since marketing creates and follows the order guide while engineering supports and utilizes the vehicle description system (VDS).

• Create separate order guides for fleet and retail customers. Much misunderstanding and many market defects result from the confusion of the present order guide. Additionally, dividing the order guide would facilitate the allocation of resources for fleet and retail customer market segments.

• Set financial goals for the de-proliferation initiative. The financial savings of de-proliferation (*i.e.*, $1 billion for 1994-1995) can be assessed by using the proforma analysis discussed in section 4.6.

• Create a gate in the concept initiation phase of the 4-phase process by which product program teams review the order guide in order to prevent unnecessary work and thus reduce program costs. Be sure that the order guide is written simply and in customer terms to provide optimal benefit to the customer.

- Shift NATP's business systems and marketing practices to produce model variants that meet regional and lifestyle variations. Focus on market sub-segments rather individuals.

- Develop a coordinated manufacturing and marketing functional strategy that emphasizes organizational strengths and identifies weaknesses.

- Implement an activity-based costing system in the assembly plants to delineate the costs of individual product features. This system will help the organization to assess the costs of adding or removing a particular product feature and evaluate its profitability.

- Appoint a de-proliferation manager within the cross-truck planning department. Report the status of de-proliferation to the executive staff every quarter during the Business Review Meetings (BRM).

# REFERENCES

Alden, J. M., and L. D. Burns. "Smoothing and Stabilizing Production Schedules." Research Report OS-121. General Motors Research Laboratories, Michigan. 1989.

Alder, U. "Automotive Handbook." Robert Bosch GmbH, Stuttgart, Germany. 1986.

Boon, Jane E. "Product Variations, Quality, and Productivity: A Cost Benefit Analysis." MSc thesis, Massachusetts Institute of Technology, Cambridge, MA. June 1992.

Dertouzos, Michael L., Richard K. Lester, Robert M. Solow. "Made in America: Regaining the Productive Edge." The MIT Press, Cambridge, MA. 1989.

Erlebacher, S. J., W. C. Jordan, and D. J. Vander Veen. "Line Balancing Accounting for Variable Processing Times." Research Report OS-198, General Motors Research Laboratories, Michigan. 1991.

Ettlie, John E., and Henry W. Stoll. "Managing the Design-Manufacturing Process." McGraw-Hill, New York. 1990.

Gilbert, C. C., R. J. Ruth, and L. A. Thelen. "The Construction of Purchase Intention and Behavior Datasets from the Allison-Fisher Survey." Research Memorandum RM30-56, General Motors Research Laboratories, Michigan. 1990.

Gleick, James. "Why We Can't Count" The New York Times Magazine. July 15, 1990.

Hax, Arnoldo C., Nicolas S. Majluf. "The Strategy Concept and Process: A Pragmatic Approach." Prentice Hall, Englewood Cliffs, New Jersey. 1991.

Jones, D. R. and W. C. Palmer. "Choosing Standard and Optional Equipment for a Car Line: The Packaging Model." Research Report SA-193, General Motors Research Laboratories, Michigan. 1986.

MacDuffie, John P., Kannan Sethuraman, and Marshall L. Fisher. "Product Variety and Manufacturing Performance: Evidence from the International Automotive Assembly Plant Study." Working Draft, The Wharton School, University of Pennsylvania, Philadelphia, PA. June 1994.

Senge, Peter M. "The Fifth Discipline." Doubleday/Currency, New York. 1990.

Spaulding, L. B. "General Motors' Component Set Strategy: A Critical Assessment of Knuckle Commonization Capability." MSc thesis, Massachusetts Institute of Technology, Cambridge, MA. May 1991.

Turnquist, M.A. and D. J. Vander Veen. "Development of an Analysis Method for Estimating Throughput and Work-In-Process Inventory of Serial Production Lines." Research Memorandum RM30-16, General Motors Research Laboratories, Michigan. 1989.

Womack, James P., Daniel T. Jones, and Daniel Roos. "The Machine That Changed the World." Harper Perennial, New York. 1991.

# APPENDIX A: REAR AXLE TREE DIAGRAM FOR 20 SERIES 2-WHEEL DRIVE 7200 GVWR FULL-SIZE PICKUP TRUCK MODELS



Proposal XXXYYY

| Engine | Trans. | Ratio | Option | C20903 (GVWR 7200) NA5 | NA6 | YF5 | Total | C20753 (GVWR 7200) NA5 | NA6 | YF5 | Total | C20953 (GVWR 7200) NA5 | NA6 | YF5 | Total | Axle Part No. | Axle Volume | Piece Cost | Depro # | Status |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LB4 | MT8 | 3.42 | &G80 | 7 | | 0 | 7 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 26028342 | 2163 | $547 | 11 | Approved |
| | | | -G80 | 16 | | 0 | 16 | 3 | 0 | 0 | 3 | 1 | 0 | 0 | 1 | 26028339 | 6622 | $467 | | |
| | | 3.73 | &G80 | 5 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 26028343 | 2655 | $547 | | |
| | | | -G80 | 13 | 5 | 1 | 19 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 26028340 | 3739 | $467 | | |
| | MG5 | 3.42 | &G80 | 15 | | 0 | 15 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 26028342 | 2163 | $547 | 11 | Approved |
| | | | -G80 | 53 | | 0 | 53 | 3 | 0 | 0 | 3 | 5 | 0 | 0 | 5 | 26028339 | 6622 | $467 | | |
| | | 3.73 | &G80 | 1 | 6 | 0 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 26028343 | 2655 | $547 | | |
| | | | -G80 | 9 | 3 | 0 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 26028340 | 3739 | $467 | | |
| | MXO | 3.42 | &G80 | 161 | | 11 | 172 | 6 | | 0 | 6 | 6 | | 0 | 6 | 26028342 | 2163 | $547 | 11 | Approved |
| | | | -G80 | 514 | | 23 | 537 | 27 | | 0 | 27 | 29 | | 0 | 29 | 26028339 | 6622 | $467 | | |
| | | 3.73 | &G80 | 14 | 21 | 0 | 35 | 5 | 0 | 1 | 6 | 0 | 0 | 0 | 0 | 26028343 | 2655 | $547 | | |
| | | | -G80 | 47 | 4 | 3 | 54 | 5 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 26028340 | 3739 | $467 | | |
| | | 4.1 | &G80 | 4 | 0 | 0 | 4 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 26028344 | 476 | $547 | 13 | Approved |
| | | | -G80 | 13 | 1 | 0 | 14 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 3 | 26028341 | 455 | $467 | 12 | Approved |
| L03 | MG5 | 3.42 | &G80 | 24 | 1 | | 25 | 0 | 0 | | 0 | 2 | 0 | | 2 | 26028342 | 2163 | $547 | 11 | Approved |
| | | | -G80 | 72 | 1 | | 73 | 5 | 0 | | 5 | 6 | 0 | | 6 | 26028339 | 6622 | $467 | | |
| | | 3.73 | &G80 | 6 | 1 | | 7 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 26028343 | 2655 | $547 | | |
| | | | -G80 | 29 | 1 | | 30 | 2 | 0 | | 2 | 2 | 0 | 0 | 2 | 26028340 | 3739 | $467 | | |
| | MXO | 3.42 | &G80 | 260 | 28 | 23 | 311 | 18 | 0 | 0 | 18 | 45 | 1 | 5 | 51 | 26028342 | 2163 | $547 | 11 | Approved |
| | | | -G80 | 1474 | 57 | 95 | 1626 | 43 | 0 | 1 | 44 | 78 | 0 | 2 | 80 | 26028339 | 6622 | $467 | | |
| | | 3.73 | &G80 | 60 | 0 | 0 | 60 | 16 | 0 | 0 | 16 | 6 | 0 | 0 | 6 | 26028343 | 2655 | $547 | | |
| | | | -G80 | 117 | 3 | 1 | 121 | 13 | 0 | 1 | 14 | 7 | 0 | 1 | 8 | 26028340 | 3739 | $467 | | |
| | | 4.10 | &G80 | 35 | 0 | 0 | 35 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 26028344 | 476 | $547 | 13 | Approved |
| | | | -G80 | 17 | 0 | 8 | 25 | 5 | 1 | 0 | 6 | 3 | 0 | 0 | 3 | 26028341 | 455 | $467 | 12 | Approved |

| Engine | Trans | Ratio | Option | C20903 (GVWR 7200) NA5 | NA6 | YF5 | Total | C20753 (GVWR 7200) NA5 | NA6 | YF5 | Total | C20953 (GVWR 7200) NA5 | NA6 | YF5 | Total | Axle Part No. | Axle Volume | Piece Cost | Depro # | Status |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| L05 | MT8 | 3.42 | [redacted] | [redacted] | | | | | | | | 9 | 0 | | 9 | [redacted] | | | 11 | Approved |
| | | | -G80 | 225 | 1 | | 226 | 62 | 1 | | 63 | 12 | 0 | | 12 | 26028339 | 6622 | $467 | | |
| | | 3.73 | &G80 | 85 | 19 | | 104 | 58 | 13 | | 71 | 24 | 4 | | 28 | 26028343 | 2655 | $547 | | |
| | | | -G80 | 176 | 85 | | 261 | 60 | 12 | | 72 | 16 | 7 | | 23 | 26028340 | 3739 | $467 | | |
| | MG5 | 3.42 | [redacted] | [redacted] | | | | | | | | 18 | 0 | 1 | 19 | [redacted] | | | 11 | Approved |
| | | | -G80 | 222 | 5 | 3 | 230 | 19 | 0 | 1 | 20 | 20 | 1 | 0 | 21 | 26028339 | 6622 | $467 | | |
| | | 3.73 | &G80 | 31 | 2 | 4 | 37 | 12 | 0 | 3 | 15 | 3 | 0 | 1 | 4 | 26028343 | 2655 | $547 | | |
| | | | -G80 | 48 | 13 | 5 | 66 | 16 | 0 | 8 | 24 | 10 | 0 | 0 | 10 | 26028340 | 3739 | $467 | | |
| | MX0 | 3.42 | [redacted] | [redacted] | | | | | | | | 211 | 2 | 11 | 224 | [redacted] | | | 11 | Approved |
| | | | -G80 | 2309 | 51 | 79 | 2439 | 462 | 7 | 53 | 522 | 366 | 2 | 27 | 395 | 26028339 | 6622 | $467 | | |
| | | 3.73 | &G80 | 501 | 19 | 46 | 566 | 858 | 27 | 260 | 1145 | 314 | 14 | 143 | 471 | 26028343 | 2655 | $547 | | |
| | | | -G80 | 963 | 105 | 178 | 1246 | 886 | 115 | 231 | 1232 | 360 | 31 | 81 | 472 | 26028340 | 3739 | $467 | | |
| | | [redacted] | [redacted] | [redacted] | | | | | | | | 62 | 17 | 17 | 96 | [redacted] | | | 13 | Approved |
| | | | [redacted] | [redacted] | | | | | | | | 49 | 15 | 3 | 67 | [redacted] | | | 12 | Approved |
| LH6 | MT8 | 3.42 | &G80 | 8 | | | 8 | 11 | | | 11 | 1 | | | 1 | 26028342 | 2163 | $547 | 11 | Approved |
| | | | -G80 | 21 | | | 21 | 3 | | | 3 | 7 | | | 7 | 26028339 | 6622 | $467 | | |
| | | 3.73 | &G80 | 1 | 0 | | 1 | 2 | 0 | | 2 | 1 | 0 | | 1 | 26028343 | 2655 | $547 | | |
| | | | -G80 | 17 | 0 | | 17 | 4 | 0 | | 4 | 0 | 1 | | 1 | 26028340 | 3739 | $467 | | |
| | | 4.10 | &G80 | | 1 | | 1 | | 1 | | 1 | | 0 | | 0 | 26028344 | 476 | $547 | 13 | Approved |
| | | | -G80 | | 1 | | 1 | | 0 | | 0 | | 0 | | 0 | 26028341 | 455 | $467 | 12 | Approved |
| | MX0 | 3.42 | &G80 | 96 | 0 | | 96 | 27 | 0 | | 27 | 23 | 0 | | 23 | 26028342 | 2163 | $547 | 11 | Approved |
| | | | -G80 | 123 | 0 | | 123 | 14 | 0 | | 14 | 18 | 0 | | 18 | 26028339 | 6622 | $467 | | |
| | | 3.73 | &G80 | 27 | 0 | | 27 | 32 | 1 | | 33 | 8 | 0 | | 8 | 26028343 | 2655 | $547 | | |
| | | | -G80 | 18 | 0 | | 18 | 16 | 1 | | 17 | 7 | 0 | | 7 | 26028340 | 3739 | $467 | | |
| | | 4.1 | &G80 | 0 | 0 | | 0 | | 0 | | 0 | | 0 | | 0 | 26028344 | 476 | $547 | 13 | Approved |
| | | | -G80 | 0 | 0 | | 0 | | 0 | | 0 | | 0 | | 0 | 26028341 | 455 | $467 | 12 | Approved |

| | C20903 (GVWR 7200) NA5 | NA6 | YF5 | Total | C20753 (GVWR 7200) NA5 | NA6 | YF5 | Total | C20953 (GVWR 7200) NA5 | NA6 | YF5 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total Model Volume: | 8647 | 517 | 519 | 9683 | 3377 | 234 | 694 | 4305 | 1735 | 95 | 292 | 2122 |

## APPENDIX B: COSTS OF A MERCHANDISING/SALES ITEM

| Incremental Cost | Informational Need | Possible Cost Driver |
|---|---|---|
| Machinery and Equipment | Machine costs | - Option type |
| Tooling | Tooling costs | - Number of parts |
| Engineering Design | Engineering drafting, specifications and release costs | - Number of parts |
| Engineering Staff | Manpower costs | - Headcount |
| Validation | Validation costs | - Number of parts<br>- Build combinations<br>- Option type |
| Sourcing and Procurement | Piece cost estimates less cost of any component replaced quantity discount ramifications | - Penetration rate<br>- Size<br>- Weight |
| Freight | Freight and shipping costs for the new components | - Penetration rate<br>- Size<br>- Weight |
| Indirect Materials | Scrap cost, indirect materials costs | - Penetration rate |
| Assembly Labor | Labor hours needed to install item at assembly plant | - Penetration rate<br>- Labor hours per item |
| Supervision Labor | Supervision labor hours per station | - Penetration rate<br>- Floor space |
| Scheduling and Control | Salaried personnel costs | - Penetration rate<br>- Number of parts |
| Maintenance and Support | Cost to maintain and support tooling and machines | - Option type<br>- Machine cost<br>- Number of parts |
| Indirect Labor | Indirect labor costs | - Floor space |

**Table D.** Incremental Costs of a New Merchandising/Sales item/option

| Incremental Cost | Informational Need | Possible Cost Driver |
|---|---|---|
| Material Handling | Capital investment in conveyors, etc. Labor hours for unloading, stocking work areas. | - Penetration rate<br>- Weight<br>- Size |
| Inventory | Work-in-process inventory levels and the dollar value at assembly plant | - Penetration rate<br>- Piece-cost estimate |
| Service Parts Inventory | Service parts inventory levels and dollar value | - Penetration rate<br>- Defect rate |
| Floor Space | Option spacing rules and factory layout | -Number of workers<br>- Inventory |
| Training | Cost to train assembly workers | - Number of assembly tasks |
| Start-Up | Industrial engineering costs to do pilot and set up assembly area | - Floor space<br>- Machine costs |
| Advertising and Marketing | Marketing costs for a truck model | - Pages in brochure devoted to option |
| Quality | Quality defects expected for the new item; Warranty costs | - Penetration rate<br>- Labor hours/piece<br>- Option type<br>- Supplier rating |
| Rework | Expected rework for the new item | - Penetration rate<br>- Labor hours/piece |
| Record-keeping and Accounting | Computer resources devoted to record keeping of parts; Salaries of accounting and computer personnel | - Number of parts |
| Utilities | Utilities cost | - Floor space |

**Table D (Continued).** Incremental Costs of a New Merchandising/Sales item/option

Table E lists some of the environmental costs associated with the introduction of a new item to the market.

| Environmental Costs | Explanation | How to measure/ Informational Needs |
|---|---|---|
| Idle Time | Idle time created by sequencing ramifications | - Simple simulation model using penetration rates |
| Quality Degradation | Complexity, chaos and inefficient communication create mistakes in both supplied quality and final quality of related components | - Cross-sectional analysis of quality versus complexity for different parts |
| Increased Inventory | Higher inventory needs due to Sequencing effects | - Cross-sectional analysis of inventories across plants |
| Diseconomies of Scope | Decreases in productivity due to reduced scale | - Time studies |

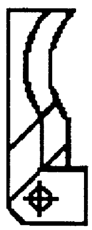
**Table E.** Environmental Costs of a New Merchandising/Sales item/option

# APPENDIX C: REAR AXLE DESIGN PARAMETERS

| Description | Classification |
|---|---|
| Spring Seat Bracket | Part |
| Jounce Bracket | Part |
| Shock Bracket | Part |
| Tube Carrier | Part |
| Differential Carrier | Part |
| Pinon Flange | Part |
| Brakes | Part |
| Axle Shaft | Part |
| Spring Seat Bracket Mounting Location from Centerline | Design |
| Jounce Bracket Mounting Location from Centerline | Design |
| Shock Bracket Mounting Location from Centerline | Design |
| Tube Carrier - Outer and Inner Diameter of Tube | Design |
| Tube Carrier - Overall Track Width | Design |
| Differential Carrier - Outer Diameter of Tube Carrier | Design |
| Pinon Flange - U-Joint Coupling | Design |
| Brakes - Load and GVWR Capacity | Design |
| Axle Shaft - Wheel Bolts Load | Design |
| Axle Shaft - Length of Axle | Design |
| Axle Shaft - Types of Brakes | Design |
| Pinon Nose Angle | Manufacturing |
| Axle Sets | Manufacturing |
| Axle Ratios | Manufacturing |
| Wheel Bolt Pattern (#) | Manufacturing |
| Locking Differential Free-Flow Option | Manufacturing |

**Table F.** Parts and Key Design and Manufacturing Parameters for Rear Axles

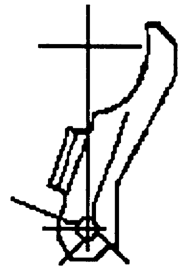
## APPENDIX D: COMPONENT STANDARDIZATION



26011828

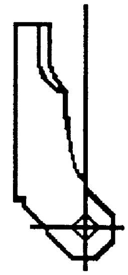
26011827

94 DISC Motorhome



26011097

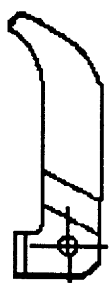
94 GMT430 C/K20-Suburban
94 GMT400 C30 SW
94 GMT400 K30 SW
94 GMT480 C30 SW
94 GMT400 C/K30 DW
94 GMT480 C/K30 DW



26012472

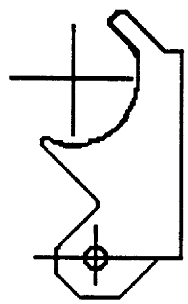
94 GMT435 C/K30 SW
N.T.

94 GMT435 C/K30 DW
N.T.



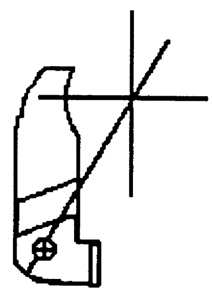
26011748

94 G-Van JB7-SW
94 G-Van JB8-SW



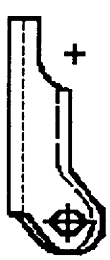
26042174

94 GMT600 SWP
94 GMT600 SWC
94 GMT600 DW7500
94 GMT600 DW8600



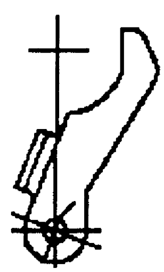
26011721

94 G-Van DW



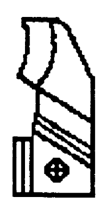
26012392

94 GMT435 C/K30 DW W.T.



26025919

94 GMT400 C20 SW-Pickup
94 GMT400 K20 SW-Pickup



3996195

94 P30 JB7-SW
94 P30 JB8-SW
94 P30 JB8-DW

**Figure 15** Current Shock Bracket Components on 10.5" Full-Size Pickup Truck Rear Axles

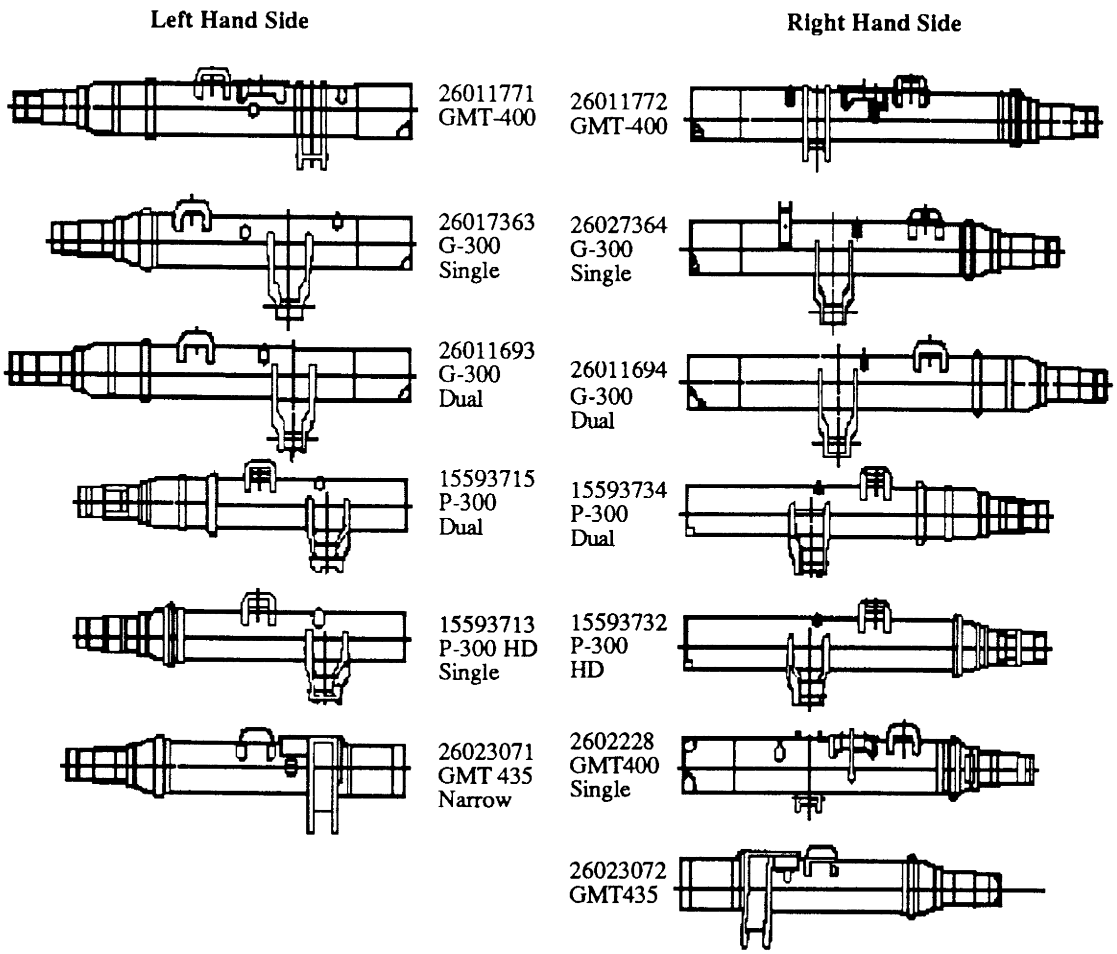



**Figure 16.** Current Axle Tube Components on 10.5" Full-Size Pickup Truck Rear Axles

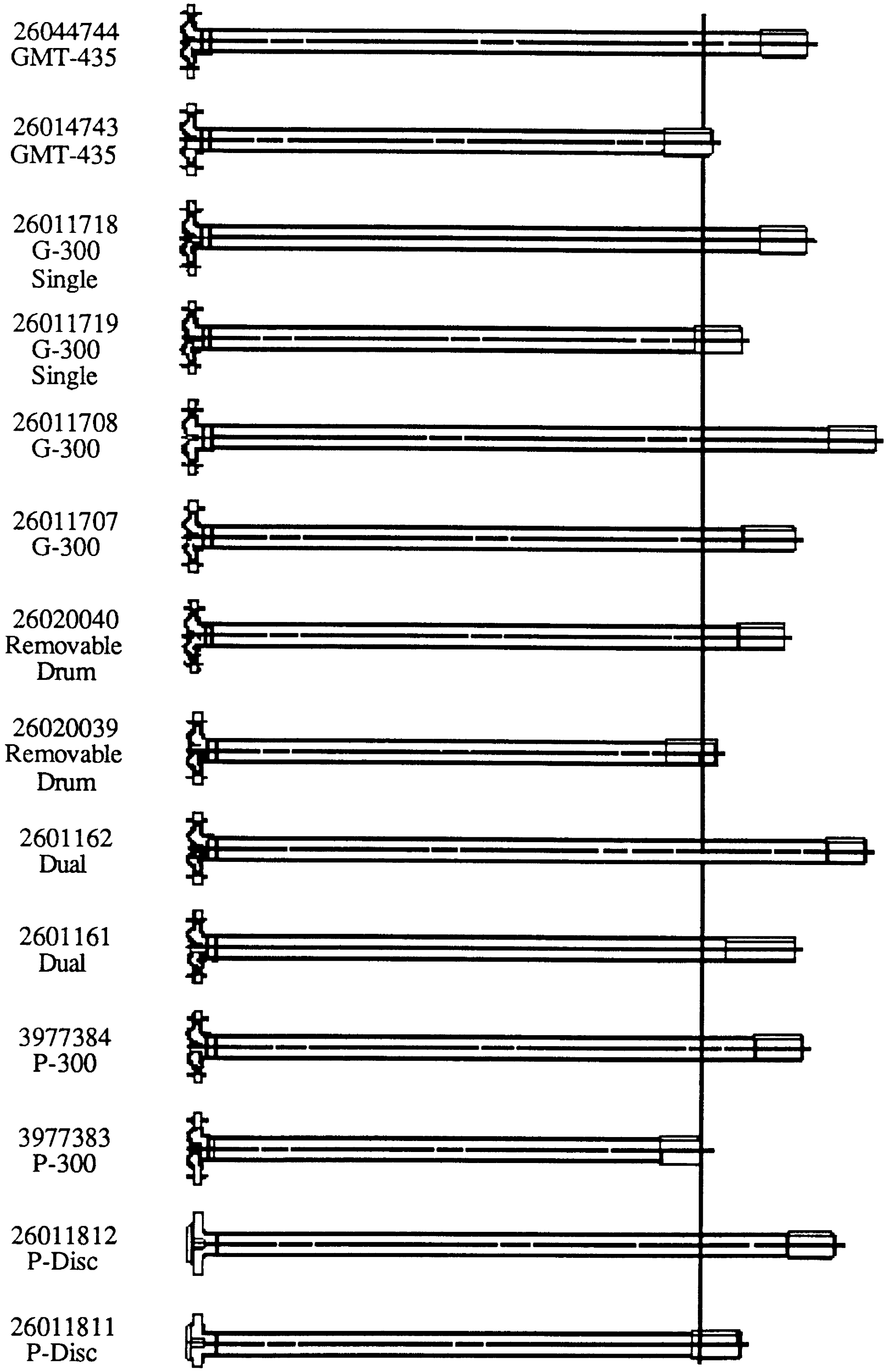



**Figure 17.** Current Axle Shaft Components on 10.5" Full-Size Picup Truck Rear Axles