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THESIS

AN ECONOMIC ANALYSIS OF COUNTERFEIT
THREADED FASTENERS IN THE
CONSTRUCTION INDUSTRY

by

Bruce Douglas Amidon

June 1990

Thesis Advisor: Paul M. Carrick

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Amidon, Bruce D.

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The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

Threaded Fasteners; Substandard Fasteners; Game Theory

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#19 - ABSTRACT - (CONTINUED)

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An Economic Analysis of Counterfeit Threaded Fasteners in the Construction Industry

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ABSTRACT

This thesis deals with the economic issues associated with the presence of substandard threaded fasteners in the construction industry. It begins with an overview of the engineering concepts and terminology which will be used throughout the remainder of the report. A short discussion is presented outlining the various mechanical forces which act upon these fasteners in order to develop an appreciation for the seriousness of the problem. Past and present problems within the fastener industry and market are also covered. The problem is then thoroughly analyzed through the use of mathematical models. The concepts of zero-sum and non-zero sum two player game theory are used to provide possible solutions to the problem.

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I. INTRODUCTION

A. OVERVIEW

Starting in the early 1980's the fastener industry, like other major U.S. industries, began to face stiff competition from overseas producers. Industry experts estimate that approximately 60 percent of the fasteners sold today come from these overseas sources. This compares to a 1969 estimate of only 22 percent.

The problem with the expansion of the "overseas connection" is two-fold. First, as suppliers turn to the lower cost foreign market--foreign bolts can be as much as 30 to 40 percent cheaper than domestic--stateside producers are forced out of business. This reduces the number of U.S. producers available should a national emergency arise.

Second, investigations conducted by members of the fastener industry have uncovered millions of "mis-marked or substandard" fasteners in use throughout the American economy. This is by far the more significant of the two issues and is the main focus of this paper. As one group of experts put it, "The real significance of the issue is, however, the crisis in confidence in reliability for users of mechanical fasteners." [Ref. 1:p. 1]

The remainder of this chapter, and the following chapter, will be devoted to technical/engineering issues. Terms used throughout the remainder of the paper will be discussed briefly. In addition, the technical aspects of the current situation will be reviewed so that the reader has a clearer understanding of the seriousness of the problem.

The third chapter will be devoted to covering the economic impacts of the issues presented in the first two chapters. This area will be looked at using several different theoretical approaches.

B. CONCEPTS and TERMINOLOGY

1. Definitions

a. Threaded Fasteners

In its purest sense, the term threaded fasteners applies to bolts, screws, structural bolts, nuts, socket screws, studs, threaded rods, and other threaded devices used to fasten two or more components together. Its use in this paper, however, will be limited to nuts and bolts. Bolts, screws and studs are said to have **external threads**; while nuts and tapped holes are said to have **internal threads**.

b. Screw Threads

Screw threads are identified under a standard system called the **Unified** System, abbreviated UN. The Unified System was adopted by the United States, Great Britain and Canada. It replaced the existing American National thread form being used by the United States and Canada and the Whitworth form used by Great Britain. Since its inception, the Unified System has gained prominence and is currently recognized as the standard throughout the world. The Unified System requires all threaded fasteners to conform to standard specifications with regards to diameter, thread height, distances between corresponding points, etc. The Unified System is further divided into dozens of different thread forms. The ones most commonly used are UN, UNR, UNJ, M, and MJ. Originally, the UN and UNR forms differed only by their root (bottom portion of the thread) design. Over the years as manufacturing processes have changed, the majority of threads produced are of the UNR form. UNJ threads are used in special aerospace applications and the M and MJ are metric equivalents of the UN and UNJ forms respectively. [Ref. 2:pp. 13-18]

In addition to thread form, thread series have also been established to distinguish between fasteners with differing number of threads per inch. The two series in use today are Unified coarse (UNC) and Unified fine (UNF). UNF threads contain more threads per inch. [Ref. 2:pp. 19-21]

c. Standards and Specifications

Mechanical properties of fasteners generally relate to their strength characteristics. The strength requirements for each grade are well standardized and defined by a number of technical organizations. Two such organizations will be referred to extensively throughout this paper.

They are the **American Society for Testing and Materials (ASTM)** and the **Society of Automotive Engineers (SAE)**.

d. Grading

Threaded fasteners are broken down into various classes, or "Grades," based upon their mechanical and/or performance properties. There are two major grading systems in use today.

The SAE grading system, the most widely referenced system in use throughout the world, designates ten different strength levels or grades in one single integrated document. Each grade is identified with a number from 1 through 8.2. Increasing numbers indicate increasing tensile strengths (the term "tensile strength" will be discussed in the following section).

Of the ten separate grades, only six are widely used. The other four, grades 4, 5.1, 7, and 8.1 apply to specialty items of limited application. [Ref. 2:p. 67]

Unlike the single integrated system developed by the SAE, the ASTM grading system references each grade to a separate published specification and they are designated by the document number of that specification. The ASTM standards provide the same basic information as contained in the SAE specifications, but contain more in-depth information for each individual grade as well as a significant amount of "boiler plate" or repetitive general information. There are definite cross references between the two standards.

No matter which specification is being used, both systems require that bolts belonging to a particular grade are identified with a Grade Identification Marking as well as a manufacturers mark which are unique to that grade and that manufacturer.

2. An Engineering Perspective

Throughout the course of this report reference will be made to certain technical/engineering attributes of threaded fasteners. While it is not essential that the reader be highly knowledgeable in this area, a familiarity with the subject will promote a better understanding of the issues at hand.

The basic function of all bolts is to act like springs, create tension in assemblies and to hold things together tightly. A bolt's ability to perform this function under various load conditions is determined by its **Tensile Strength**. The tensile strength of the different bolt grades is determined by the material, or alloys, which went into fabrication and the final treatment process performed. The various treatment processes available are: cold working; quenching; and tempering. Quenching involves heating of the steel to a high temperature and then cooling it quickly by immersion in water or oil. This results in a harder, stronger steel. It also creates a buildup of internal stresses within the material which cause it to become brittle. The tempering process reheats the metal to a somewhat lower temperature followed by a slow cooling. Tempering is designed to relieve the built-up internal stress created during quenching and soften the material. The end result of the two processes is a material that is stronger yet tougher due to the reduction of internal stresses. [Ref. 3:pp. 431-432] It is important to remember that any treatment process will alter the tensile strength properties of a given material composition.

As a bolt-nut combination is tightened the bolt develops an initial tensile load, or "preload" due to the elongation of the bolt and compression of the joined material (see Figure 1). This preload (P) is in equilibrium with the forces exerted by the material being joined (F). As service loads are applied, additional forces act upon the bolt to cause further elongation.

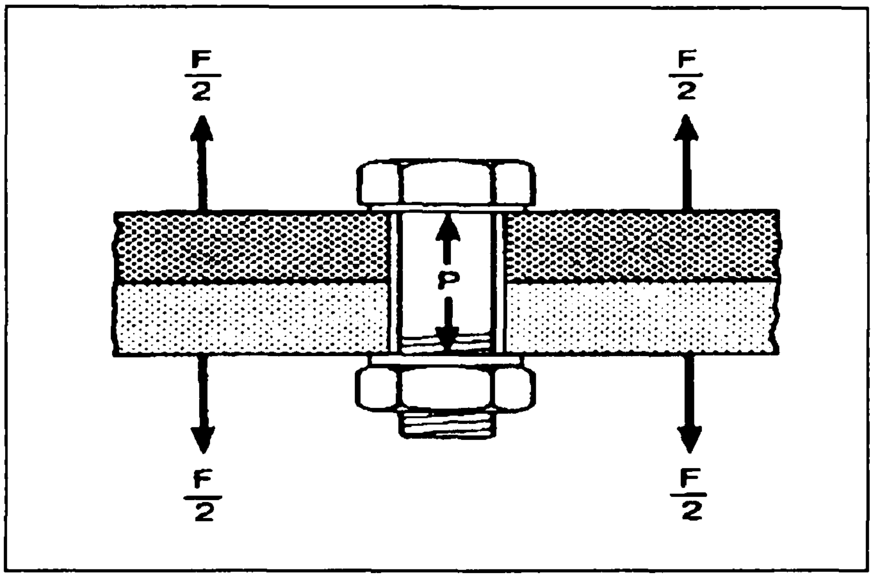

Figure 1. Bolted Joint, Externally Loaded [Ref. 4:p. 58]

Initially, as loads are applied, the bolt will elongate elastically. This means that once the load is removed, the bolt will return to its original dimensions. Elastic elongation, or "deformation" as it is more commonly called, will continue until load is applied equal to the **Yield Strength** of the material. At this point the bolt will no longer "deform" elastically, but will enter the **Plastic Deformation** region. Once a bolt enters the plastic deformation region it will no longer return to its original dimensions after the load is removed and the rate of elongation increases. Elongation continues until the materials tensile strength is reached. At this point failure occurs and the bolt breaks. [Ref. 4:p. 56] Figure 2 shows graphically the relationship between tension load and elongation for three separate grades of bolts.

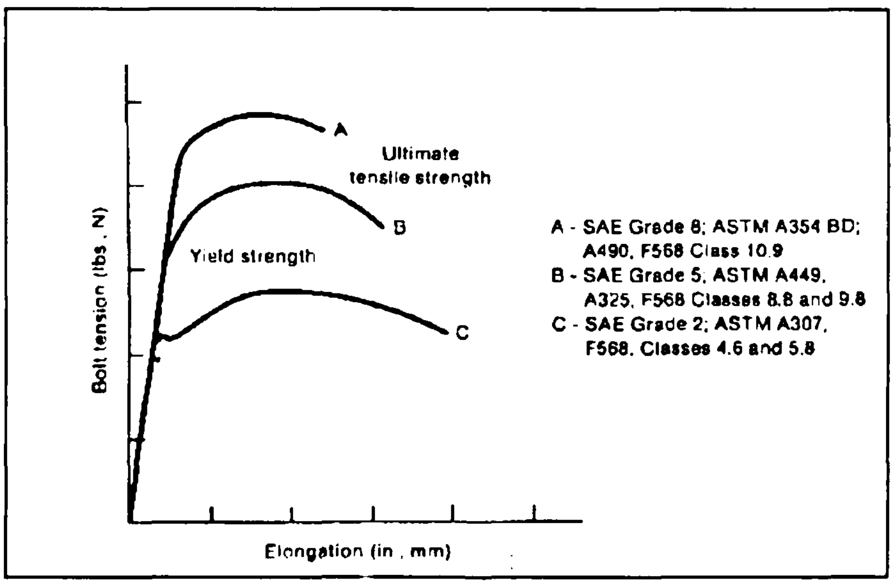

Figure 2. Typical Load-elongation Behavior of Bolts in Tension [Ref. 4:p. 56]

Therefore, the rated tensile strength is a measure of the amount of loading, or elongation, a particular grade of bolt is able to handle before it fails. In other words, "tensile strength is the amount of resistance a material has to being pulled apart." As the diameter of a bolt increases, resulting in a corresponding increase in cross-sectional area, its ultimate tensile strength increases. Tables I and II list the mechanical requirements and chemical compositions for carbon steel bolts using the SAE grading system. Under the column titled "Tensile Strength, Minimum" values are given for the various grades of bolts. The measurement units of "ksi" stands for thousand pounds per square inch. These values can be converted into a total load value by multiplying the number given by 1000, then multiplying this result by the tensile stress area corresponding to the diameter of the bolt in question. Tensile stress area values can be found in "Thread Stress Area" tables which have been developed for both UNC and UNF thread series. This value corresponds to the cross-sectional area of the bolt, which is calculated by using the outer thread diameter.

Once engineers have determined the amount of pulling force present in a particular application, they can use these calculations to determine the number and size of bolts necessary to accomplish the job. While a certain factor of safety goes into any design calculation, if the engineer specifies a design requiring six, Grade 8, bolts and the contractor installs something less, a catastrophic failure could result.

A close examination of Table I will show that SAE specifications are limited to a maximum bolt diameter of one and one-half inches. Also, the mechanical requirements for all SAE grades are condensed into one chart. This is not the case for ASTM specifications. Each ASTM grade of bolt is covered by a separate ASTM document comprising three to five pages of information. For comparison purposes, the ASTM specifications for A325 bolts (commonly used in construction applications) has been reproduced in Table III. Although not shown in Table III, the ASTM specifications go into much more detail than the SAE specifications. In addition to the data shown, each ASTM specification document also addresses other areas such as: ordering information; manufacturing processes; heat treatment; and product analysis. The complete ASTM specifications also covers a larger number of grade classifications than the ten grades listed in the SAE specifications. [Ref. 6]

Where a cross reference exists between the two specifications, the information contained in each is comparable (i.e., the minimum strength values match with no contradiction). The ASTM specifications will not be reproduced in their entirety in this report due to the vast amount of information contained within them. For further information on ASTM specifications the reader is directed to Reference 6.

TABLE I

MECHANICAL REQUIREMENTS FOR
BOLTS, SCREWS, STUDS, STEMS, AND U-BOLTS

GRADE	NOMINAL DIAMETER (inches)	PROOF LOAD STRESS ksi	YIELD STRENGTH ksi minimum	TENSILE STRENGTH ksi minimum
1	1/4 thru 1-1/2	33	36	60
2	1/4 thru 3/4	55	57	74
4	1/4 thru 1-1/2	N/A	100	115
5	1/4 thru 1 1 thru 1-1/2	85 74	92 81	120 105
5.1	No. 6 thru 3/8	85	N/A	120
5.2	1/4 thru 1	85	92	120
7	1/4 thru 1-1/2	105	115	133
8	**1/4 thru 1-1/2**	**120**	**130**	**150**
8.1	1/4 thru 1-1/2	120	130	150
8.2	**1/4 thru 1**	**120**	**130**	**150**

Source: [Ref. 5:p.125]

TABLE II

CHEMICAL COMPOSITION REQUIREMENTS

GRADE	MATERIAL and TREATMENT	COMPOSITION, % C Min	C Max	Mn Min	P Max	S Max	B Min
1	Low or medium carbon steel	N/A	0.55	N/A	.048	.058	N/A
2	Low or medium carbon steel	N/A	0.28	N/A	.048	.058	N/A
4	Medium carbon cold drawn steel	N/A	0.55	N/A	.048	.058	N/A
5	Medium carbon steel quenched & tempered	0.28	0.55	N/A	.048	.058	N/A
5.1	Low or medium carbon steel quenched & tempered	0.15	0.30	N/A	.048	.058	N/A
7	Medium carbon alloy steel quenched & tempered	0.28	0.55	N/A	.040	.045	N/A
8	Medium carbon alloy steel quenched & tempered	0.28	0.55	N/A	.040	.045	N/A
8.1	Elevated temperature drawn steel, medium carbon alloy	0.28	0.55	N/A	.048	.058	N/A
8.2	Low carbon martensite steel, fine grained, quenched & tempered	0.15	0.25	0.74	.048	.058	.001

Note: C = Carbon; Mn = Manganese; P = Phosphorous; S = Sulfur; and B = Boron.

Source: [Ref. 5:p. 126]

TABLE III

TENSILE REQUIREMENTS FOR SPECIMENS AND CHEMICAL REQUIREMENTS FOR A325 BOLTS

GRADE	NOMINAL DIAMETER (inches)	PROOF LOAD STRESS, ksi	YIELD STRENGTH, ksi minimum	TENSILE STRENGTH, ksi minimum
A325	1/2 thru 1	85	92	120
	1-1/8 thru 1-1/2	74	81	105

GRADE	MATERIAL and TREATMENT	COMPOSITION, % C Min	C Max	Mn Min	P Max	S Max	B Min
A325 Type 1	Medium carbon steel quenched & tempered	0.25	0.58	0.57	.048	.058	---
Type 2	Low carbon boron steel quenched & tempered	0.13	0.41	0.67	.048	.058	.001
Type 3	Atmospheric corrosion resistant steel quenched & tempered	0.31	0.42	0.86	.045	.055	---

Note: In addition to the above elements, Type 3 bolts also contain the following elements: Silicon, 0.13-0.37%; Copper, 0.22-0.48%; Nickel, 0.22-0.48%; and Chromium, 0.42-0.68%.

Source: [Ref. 6:pp. 56-58]

II. THE DILEMMA

A. HISTORICAL BACKGROUND

The Industrial Fastener Institute (IFI) is an association of leading North American fastener manufacturers which was established to promote technical excellence and engineering within the fastener industry. Working closely with technical societies and organizations, they help to develop fastener standards and technical practices. IFI acts as an information processing and clearing house rather than a governing body. Through newsletters and advisory notices, IFI keeps its members informed of current events and issues affecting their industry, and represents its members on issues of vital industry significance. IFI has no policing powers and is therefore unable to rectify any improprieties taking place within the industry, other than informing its members that particular problems do exist. In addition, it has no impact on overseas manufacturers.

In 1985, IFI learned that significant numbers of substandard, mismarked and counterfeit fasteners had been entering the market for the past several years. Substandard refers to those fasteners that are manufactured in violation of current SAE or ASTM specifications for tolerances, either during the manufacturing process or as a finished product. Mismarked and/or counterfeit fasteners are those fasteners which contain alloys or compositions corresponding to a particular grade but are marked as being of a higher/stronger grade. After conducting their own investigation into the issue, IFI identified the following concerns:

a. The countries involved in manufacturing the faulty fasteners are: Korea, Taiwan, Japan, and Poland. [Ref. 7:p. 2]

b. The fastener grades most often affected are: SAE Grade 8 and SAE Grade 5. Grade 8 bolts are used extensively in manufacturing of heavy equipment such as vehicles and aircraft engines.

c. Testing of 300 product samples taken from various geographical areas throughout the United States indicate that the number of out-of-spec Grade 8 bolts in existence could be as high as 70 percent or over one billion bolts. [Ref. 7:p. 5]

d. With an estimated usage of nearly eight billion bolts annually, approximately 20 percent are the Grade 8 type (roughly 1.5 billion). [Ref. 1:p. 3]

Once their preliminary investigations identified the magnitude of the problem, IFI began to delve further. Follow-on investigations focused on three major problem areas: (1) nuts have been discovered with oversized threads which allows them to mate easily with their companion bolts but results in stripping of the threads under load conditions (example of substandard products); (2) the performance-indicating head-marks do not accurately reflect the material content of the bolt; and (3) material substitutions have taken place during processing that causes the material to react improperly during heat treating or hot galvanizing.

Of these three areas, the third one, material substitutions, has been the focus of numerous tests and evaluations. Specifically, investigators have discovered that a significant number of bolts identified as the high strength, medium carbon alloy steel bolts (SAE Grade 8) are in reality the lower carbon boron steel Grade 8.2 bolts. While both have identical tensile strengths, as Table I shows, 8.2 bolts are limited to one inch in diameter. In addition, grade 8.2 bolts are seriously affected by high temperatures.

At temperatures greater than 200 degrees [C] (392 degrees [F]), the low carbon martensite composition of Grade 8.2 bolts looses hardness in a very short period of time due to coalescence of the particle structure (the deterioration process is even faster at higher temperatures). Coalescence is the process whereby the material structure changes from many small particles to fewer, larger particles. Larger particles allow any "cracks" resulting from applied loads to propagate (i.e., grow) much faster than will occur with smaller particles. As hardness decreases there is a corresponding decrease in tensile and yield strengths. [Ref. 3:p. 216] Figure 3 provides a graphical representation of the rate at which hardness (and by association tensile strength) is lost at various temperatures.

Temperatures of this magnitude are found in numerous applications--boilers and automobile and aircraft engines for example--as well as certain manufacturing processes. A

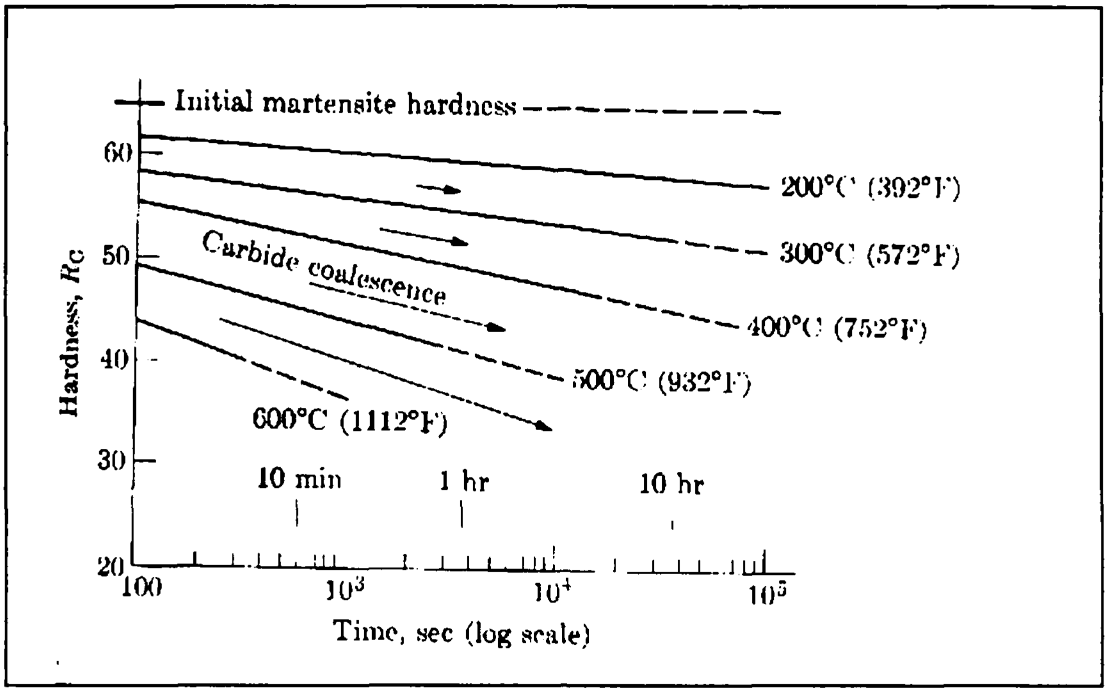

Figure 3. Softening of Steel at Elevated Temperatures [Ref. 3:p. 399]

standard weatherproofing process consists of dipping the bolts into a molten galvanizing solution which subjects them to temperatures in excess of 800 degrees [F]. If users unknowingly install Grade 8.2 bolts (which have been falsely labeled as Grade 8) in high service temperature applications, or dip them in molten galvanizing solution to enhance corrosion resistance, a significant problem will occur as the bolts begin to loose their properties at the elevated temperatures. Specifically, the bolt will begin to relax or stretch and lose its ability to fasten the joint together. Hot galvanizing of an 8.2 bolt, thought to be Grade 8, will cause it to become brittle on the outside and soft on the inside. [Ref. 7:p. 4] This will cause it to stretch and break under stress. Either of these changes could result in failure of the entire assembly.

The force driving manufacturers to knowingly substitute grade 8.2 bolts for grade 8 is cost (more specifically, profit). Referring back to Table II, SAE specifications allow the use of boron and manganese in the 8.2 bolts. Both elements are cheaper to obtain than carbon. The end result is a bolt that is cheaper to produce being sold at a premium price which leads to increased profits. A similar condition exists when A325 Type 2 bolts are substituted for A325 Type 1.

In both situations, the only way the end-user can distinguish between the two types is to have spectrochemical analysis run on representative samples. This analysis provides a detailed breakdown of the samples composition but is quite costly when compared with the unit cost of the fasteners. An alternative testing method that is being offered is **Eddy Current Comparator Testing.** While less expensive than spectrochemical testing, it provides only limited results. It can only determine if the composition of a test sample is different than a known standard. It does not identify what the differences are. [Ref. 8:pp. 86-87]

Since 1985 much attention has been focused on the Grade 8 vs. 8.2 issue. Sample tests have been conducted on bolts taken from all parts of the country and all types of industry. In 1987, congressional hearings were conducted by the

Subcommittee on Oversight and Investigations of the Committee on Energy and Commerce, House of Representatives. These hearings identified four major factors that allow the problem to continue: (1) distributors are relying solely on the certificates of compliance provided by the manufacturer and do not conduct their own incoming inspections; (2) end-users are not conducting their own incoming inspections (they assume a quality product is being provided by the distributor); (3) when incoming inspections are performed, they are not always accurately conducted; and (4) the procurement chain for foreign supplied fasteners is so complex there is a definite loss of traceability between the manufacturer and end-user (See Figure 4). [Ref. 9:pp. 91-93] Ignoring economizing concerns, the ideal system would be one where the manufacturer supplies directly to the end-user thereby cutting out all middle-men. This would give the user a direct link so that he could ensure adequate quality control and documentation. It would also provide for immediate compensation if substandard fasteners are discovered. Unfortunately, this system would be highly impractical. Manufacturers produce fasteners in lot sizes ranging into the hundreds-of-thousands while end-users purchase fasteners in lots ranging into the tens-of-thousands in some cases, but even smaller in most cases.

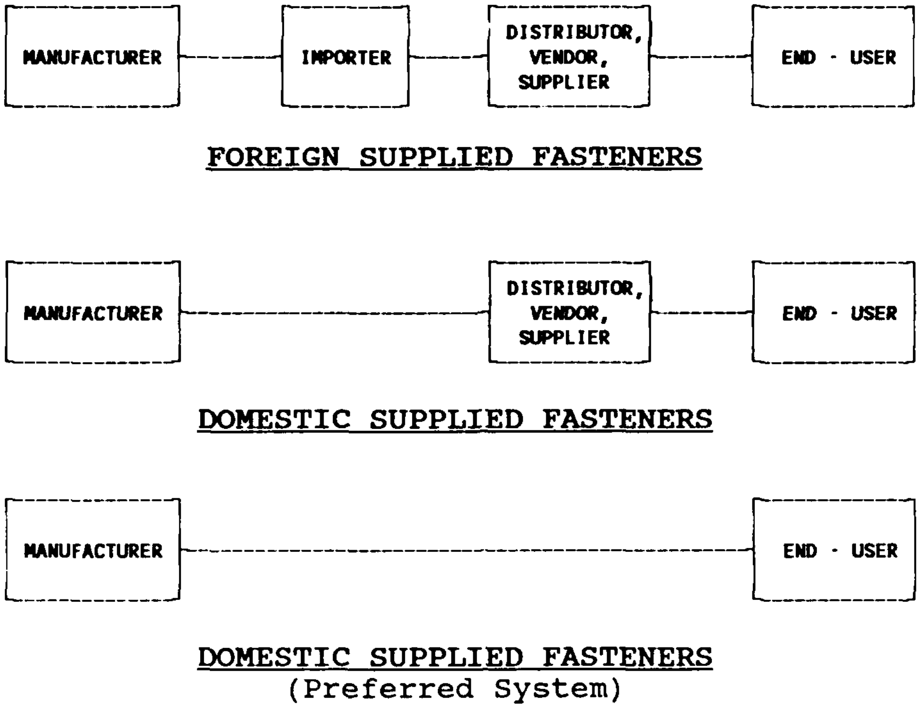

Figure 4. Examples of Fastener Procurement Systems [Ref. 8:p. 90]

B. CURRENT CONCERNS

While extensive investigations have been conducted to determine the magnitude of the problem, only cursory attention has been given to the economic impact. Specific cases were identified during the congressional hearings where the discovery of substandard fasteners at construction sites resulted in the replacement of tens-of-thousands of bolts and nuts. In all cases there were costs associated with the varying amounts of rework required to replace the defective fasteners. Some contractors were able to return the faulty fasteners for full refund while others had to accept the loss associated with scraping the material. Irregardless, rework costs were borne by the contractor.

Although some cases resulted in fines being levied to unscrupulous suppliers, the majority of the incidents only involved the replacement of the fasteners. The issue of dollars lost to both the suppliers and end-users has not been adequately addressed. The remainder of this report will focus on the economic issues involved in the buyer-seller relationship.

III. THE ECONOMIC ISSUES

A. MARKETING THEORY

In the previous chapter, Figure 4 identified three different marketing scenarios. At the time, it was implied that the optimal system, from the standpoint of minimizing the risk of receiving counterfeit fasteners, was a direct manufacturer to end-user marketing system. This would provide an unencumbered link between the source and the end-user whereby traceability could be easily maintained.

Traceability is one of the key elements in reducing the occurrence of counterfeit fasteners. The ideal system, again from the standpoint of eliminating counterfeit components, would be one in which each nut and bolt is accompanied by documentation showing its lineage. If the end-user is able to track faulty components back to the source, it will provide him with the ability to seek restitution quickly and easily. It will also readily identify the manufacturers who engage in unscrupulous practices so that use of these sources can be curtailed. The current system where importers and distributors act as intermediaries makes tracking extremely costly and difficult. At each stage of the process any potentially counterfeit components can be intermingled with legitimate ones.

The direct manufacturer to end-user scenario is only a desirable alternative from the standpoint of improving traceability. In reality, from a marketing standpoint this system would be uneconomical and unmanageable. In real world applications, distributors, wholesalers and retailers play a key role in the marketing system.

These marketing intermediaries are able to reduce the aggregate cost of distribution by reducing the number of transactions taking place. If each manufacturer sold directly to each consumer the number of **contact lines** would grow rapidly. Interjection of a distributor or wholesaler to act as an agent between the various parties will substantially reduce the number of contact lines. [Ref. 10:p. 6]

In addition to improving efficiency, the marketing intermediaries also provide a **sorting** function. By doing so, they help bridge the gap between the varieties and quantities of items demanded by a consumer and those generated by producers. Sorting activities provide a smooth conduit whereby consumers can obtain small quantities of a wide variety of goods from various manufacturers, each producing large quantities of a limited variety of goods [Ref. 10:p. 6].

Both the ability to improve transaction efficiency and provide the needed sorting capabilities ensure that marketing intermediaries play an important role in increasing market efficiency. Elimination of these intermediaries in order to attack the potential economic losses associated with obtaining counterfeit fasteners could be a serious economic mistake. Consumers <u>might</u> only be trading one economic loss for another but there is insufficient data to say undeniably which of the two would pose the greater economic loss.

B. ECONOMIC STRATEGY

Having eliminated direct marketing as a potential cure for the problem, we must now focus on the issues that cause the supplier to provide counterfeit substitutes in an otherwise competitive market (as used throughout the remainder of this report, the term "supplier" will include both manufacturers and intermediaries). The basic premise will be, "What drives a supplier to disrupt the **Pareto Efficiency** of the market place by introducing counterfeit fasteners?"

In a Pareto-Efficient economy, the buyer-seller relationship is such that resource allocation (i.e., supply vs. demand) is at an optimal level. This "Pareto-optimal" (or "Pareto-efficient") allocation is the level at which: **there is no rearrangement of resources (no possible change in production and consumption) such that someone can be made better off without, at the same time, making someone else worse off** [Ref. 11:p. 63]. Refering back to the section on **Current Concerns** in the previous chapter, one can easily see that the dilemma currently facing users of threaded fasteners from this efficient level. While a few suppliers are able to make themselves better off, by increasing their profit margin through the use off counterfeit fasteners, they are doing so at the expense of the consumer (or end-user). The consumer is forced to either accept the increased risks involved with unknowingly using substandard fasteners, or incur increased inventory costs by spending additional dollars on part inspections and tests upon receipt of their merchandise.

At this point, one may ask, "Why doesn't the government intercede to eliminate the problem?" Many economists would classify the current situation as a "market failure caused by **negative externalities"** (negative externality refers to the situation where the **actions of one individual or firm imposes a cost on other firms but does not compensate the other firms** [Ref. 11:p. 75]). In this particular case, the negative externality is the availability of counterfeit fasteners. Currently, a few sellers are able to engage in an excessive use of counterfeit fasteners because they are not being forced to bear the full cost of such actions. The only potential cost to them is lost business. It appears that there are sufficient numbers of buyers available such that the loss of one or two customers will not severely impact business. Stiglitz [Ref. 11] implies that this is a textbook case for government intervention. Two options that could be used are government regulations and/or use of the system to impose fines or penalties.

Although the pros and cons of government intervention will not be addressed, it should be pointed out that some action is currently taking place at the various levels of government. For example, at the activity level, the Defense Industrial Supply Center (DISC) is making use of an existing government program to help reduce the risk of receiving counterfeit fasteners. The **Government-Industry Data Exchange Program (GIDEP)** is a government data base which is accessible by government agencies and industries involved in government contracts. The data base acts as a feedback system whereby firms or agencies can issue and receive reports covering a multitude of issues, one of which is supplier related faulty fastener problems. Although the GIDEP system does not generate a **Blacklist** of problem suppliers, it does inform those using the system of suppliers which have been known to provide faulty components (in all fairness, the GIDEP system does give any supplier identified the opportunity to respond to any allegations). This system allows the government to assess a penalty on the nonconforming supplier. In this case, the penalty is wide publication connecting his company with faulty fasteners. This will significantly increase the economic losses to those firms caught cheating the system. While GIDEP has reduced the risk and/or liability to those firms using it, it is not the ultimate panacea. While eliminating some of the risk, there are added costs involved. Organizations such as DISC and private contractors have been forced to tighten their requirements on any, and all, fasteners they procure. The number of receiving inspections being performed has increased significantly. Should a particular firm discover nonconforming pieces as a result of one of these inspections, he may then file a report identifying the problem with the specific lot from a given supplier. The report may then force other firms to perform additional testing on other lots which they may have received from the same supplier. This snowball effect is not without added cost.

In addition to the increased costs associated with added receiving inspections, consumers, aware of the potential risks involved, are forcing their suppliers to provide higher quality control on the components they ship. Consumers are also forcing the suppliers to provide testing/conformance documentation with each lot purchased. As tighter controls are placed upon the suppliers, the unit costs to the consumer are raised to compensate the supplier for his time.

One gentleman contacted at DISC commented that the solution to the problem should be to "put more quality into the product vice monitoring the product upon receipt" [Ref. 12]. Unfortunately, the solution is not as easy as it may appear. One of the ways in which some suppliers are allowing nonconforming fasteners to enter the market place is by providing forged documentation with the components. The forged documentation would lead the consumer to think that all of the required quality control had been done when, in reality, it had not. This is just another facet of the problem. [Ref. 9:p. 104]

In addition to programs being developed and used at the activity level, steps are being taken to combat the problem by the legislative branch of the federal government. Over the past several years, Congress has considered legislation to help control the problem. The most recent bill to come up before the legislature is H.R. 3000, the "Fastener Quality Act." The bill is worded as follows:

> To require that certain fasteners sold in commerce conform to the specifications to which they are represented to be manufactured, to provide for accreditation of laboratories engaged in fastener testing, to require inspection, testing, and certification, in accordance with standardized methods, of fasteners used in critical applications to increase fastener quality and reduce the danger of fastener failure, and for other purposes. [Ref. 13]

The intent of this bill is to protect the end-user by placing specific requirements on transactions involving threaded fasteners. The following areas are covered under this bill: (1) testing and certification; (2) accreditation of testing laboratories; (3) guidelines pertaining to the documentation that must accompany the sale of any large quantity of fasteners; and (4) requirements for manufacturers' markings on each fastener produced. In addition to providing specific guidelines covering the transactions, H.R. 3000 also provides for civil and criminal penalties to anyone found violating any of the regulations. The government is attempting to attack the problem from both fronts. First, by increased regulations which make it harder for suppliers to cheat the system. Second, by severely penalizing those that do chose to run the risk.

Although the intent of the Bill is sound and it appears to cover all of the major areas of contention, policing the players involved could become an expensive and time-consuming proposition. However, as we shall see in the following section, the risk associated with the imposition of penalties to those suppliers found in violation of the Bill does provide an added factor that must be considered.

C. GAME THEORY AND THE STRATEGY OF CONFLICT

Perhaps the best way to analyze the current dilemma is through the use of a strategy concept known as **Two-Person Game Theory.** Game theory is the process whereby a theoretical mathematical model is developed to analyze human behavior and decision-making as they apply to problems obtained from real life situations. The "Game" itself is defined by a set of rules, or options, that apply to the situation under review. In all cases, decisions are required from two or more "players" (the term is used to indicate the agents involved in the particular situation) to arrive at the final outcome. The outcome is in the form of a payoff determined by the actions chosen. The payoff to each player is based not only upon his selection but also by the choice of strategy the other player has selected.

The rules of the game can be either explicit or implicitly applied. If the rules allow for communication between the players, as well as for the possibility of binding contracts, then it is called a **cooperative game.** If communication between the players is not allowed or is not desired then it is considered a **noncooperative game.** [Ref. 14:p. 15]

1. <u>The Zero-Sum Game</u>

The simplest form of two-person game theory is the Zero-Sum Game. Under this scenario, the gain to one player from selecting one of his previously identified strategies is exactly offset by an equal loss to the other player, and vice versa. In order to make the discussion more applicable to the current situation, we will assume that a player's choice on a given "move" will remain unknown to the other player. For simplicity, each player will have only two options from which he may pick. To assist in analyzing the problem we will be using the game matrix shown in Figure 5.

		Player One	
		I	II
Player Two	A	-2, 2	4, -4
	B	2, -2	-1, 1

Note: First payoff in each box is to the row chooser; the second to the column chooser.

Figure 5. Zero-Sum Game Matrix [Ref. 15:p. 67]

As the game matrix shows, player one has the option of choosing one of two strategies, 'I' and 'II.' Likewise, player two has a similar choice of strategies, 'A' and 'B.' Under normal circumstances, neither player will be told which strategy the other has selected, therefore it is a noncooperative game. Focusing in on player two, in making his selection he may apply one of three possible principles: (1) choosing the strategy with the biggest payoff--'A'; (2) choosing the strategy which contains the highest average payoff (this assumes that either selection is equally probable)--'A'; or (3) choosing the strategy which contains the "best of the worst" (also known as minimax)--'B.' He must make his choice in this manner because their exists no **dominating strategy** for either player. A dominating strategy occurs when there is a higher payoff for a given player no matter what strategy is selected by the other player [Ref. 14:p. 16]. An example of such a game could be made by changing box 3 of Figure 5 from 2,-2 to -3,2. This would make player one's selection of strategy 'I' and player two's selection of strategy 'A' the best choice for each no matter which choice the other made. Under the current conditions however, if player two hopes to secure any sort of an advantage, he must fully analyze the implications of his actions. [Ref. 15:p. 67]

Starting with a provisional selection of 'B,' player two must then ask himself what player one would do if he knew of this decision. Obviously, player one would select strategy 'II' for it gives him the highest possible payoff of '1.' The problem continues with this "what he would do if he knew that I know that he knows...." type of approach. At this point, one would tend to believe that there is no clear-cut conclusion. Player two can overcome this problem through a new tactic known as **mixed strategy.**

The fundamental purpose of mixed strategy is to keep your opponent off guard by randomly selecting between the two strategies. Assuming that the probabilities associated with each choice are equal (i.e., 50-50) then in the long run player two would choose strategy 'A' half of the time and strategy 'B' the other half. A similar situation exists for player one and strategies 'I' and 'II.' Because the selections are made independently, the law of probabilities dictates that each of the four outcomes will occur 25 percent of the time. This will result in an average long-term payoff to player two of $[.25(-2) + .25(4) + .25(2) + .25(-1)] = .75$ units per play with an equivalent loss to player one. [Ref. 15:p. 71] Under the 50-50 selection option, this is the most that can be won or lost by either player. Deviations from the 50-50 selection option will alter the outcome depending upon the extent of the deviation. Therefore it is in each player's best interest to determine the one selection strategy that provides him with the best expected long range outcome.

Through the use of his mathematical model, Rapoport [Ref. 14] came up with the optimum mixture for each player. Player two would guarantee himself an expected gain of 2/3 units by utilizing a 1/3, 2/3 mixture independent of the options selected by player one. This means that he would select strategy 'A' one out of every three times and strategy 'B' two out of every three times. One must keep in mind that although the proportions are mandated by the model, they must be carried out in a random pattern. Player one will also be able to guarantee himself a minimal loss of 2/3 by using a 5/9, 4/9 mixture. There is nothing either player can do to improve upon this outcome as long as both players are assumed to be rational in their selections. It is important to note, that these are long term outcomes from many iterations and can not characterize the result of any single play of the game. [Ref. 15:p. 74]

2. The Non-Zero Sum Game

In the zero-sum game previously discussed, the gain to one player is exactly equal to the loss to the other player. In reality, this is not always the case. Games of strategy in which the losses are not equal and opposite to the gains are known as **Non-Zero Sum Games.** In the zero-sum game the interests of the two players are determined to coincide completely, resulting in equity. However, in the non-zero sum game the interests of the players partly coincide and partly conflict. [Ref. 15:p. 95]

Most transactions currently taking place in the U.S. marketplace are based upon a self-enforcing agreement between the two players. It is not necessary to develop the noncooperative equilibrium condition for cases such as these.

As the name implies, self-enforcing agreements are ones in which the parties involved must make the determination as to whether or not a violation of the current cooperative agreement has occurred. There is no reliance upon a "neutral third party" to determine if a violation has taken place and to assess damages that may be attributed to such a violation. Violation of the agreement by one of the parties would normally lead to termination of the agreement by the other. In the case of the counterfeit fastener dilemma currently under discussion, if the supplier were to violate the agreement by providing the consumer with fasteners of a lesser quality then originally requested, then the consumer would cancel the existing contract and probably refuse to do any future business with the supplier. By doing so, they are able to eliminate any additional costs associated with third party intervention (i.e., legal fees, court costs, etc.). However, mere canceling of the contract may not be a sufficient enough penalty to deter the supplier from pulling this same scam on some other unsuspecting buyer in the future.

In order for self-enforcing agreements to work, each party must determine whether or not he gains more from continuing with the agreement or from violating it. As long as both parties feel there is more to be gained from adhering to the agreement, the agreement will stay in force and the market will be free to operate at its pareto-efficient level. [Ref. 16:p. 187] In essence, because of the limited amount of information available to the buyer, he must rely upon the trustworthiness of the seller. On the other hand, the seller will only be trustworthy if he feels that his honesty will pay more in the long run.

In the case of counterfeit fasteners, if the seller cheats and is not caught, he will gain by an amount equivalent to the increased profits he receives from selling a lower quality product at a higher quality price. If the seller cheats and is caught, under current practices he will only lose an amount equivalent to the future business of the buyer. If the transaction currently in progress is the final transaction between the two parties, there will be no future loss to the seller. The loss to the buyer is more difficult to determine since it contains certain intrinsic values associated with risk and liability which are difficult to measure.

a. Prizzi's Honor

Perhaps the best way to describe the situation is to provide an example using a Non-Zero Sum Game Theory known as **Prizzi's Honor.**

For simplicity we will asume that only two alternatives are available to each party. We start our discussion by defining these two options (i.e., the rules of the game). First, player number one, the buyer, can either inspect or not inspect representative samples from each lot he receives. If he chooses to inspect, he will incur additional inventory costs associated with whatever inspection process he selects. If he chooses to not inspect, there will be no added inventory costs.

Second, player number two, the seller, can either cheat, and provide nonconforming fasteners, or not cheat. In either case he will claim that he has not cheated. If he chooses to cheat, he has a potential gain associated with the increased profits. If he chooses not to cheat, then he will make the normal profit associated with the prices set in the marketplace.

Figure 6 *shows a payoff matrix* for the buyer and the seller. If the buyer doesn't inspect and the seller doesn't cheat, then the return to each is their normal base amount (identified as zero). The seller would be able to successfully cheat the buyer if the buyer does not inspect. In this case, the gain to the seller is defined as "d_2" which is equal to the loss to the buyer ($-d_2$). If, on the other hand, the buyer chooses to inspect but the seller opts not to cheat then the seller will still receive his base amount but the buyer is out the amount of the inspection, identified as "$-d_1$."

SELLER	BUYER: Don't Inspect	BUYER: Inspect
Don't Cheat	0, 0	0, -d1
Cheat	d2, -d2	-d3, d3 - d1

Note: First payoff in each box is to the row chooser; the second to the column chooser.

Figure 6. Prizzi's Honor Game Matrix [Ref. 16:p. 201]

The final square is the one of most interest. In this case, the seller decides to cheat but is caught by the inspecting buyer. We assume that a new cost has entered into the picture, represented by "d_3." This cost is a penalty, or fine, placed upon the seller for his unscrupulous actions. When caught, the seller must make restitution for the nonconforming fasteners as well as paying a penalty to the buyer. The buyer than gains the amount of the penalty, less any costs associated with the inspections $(d_3 - d_1)$. [Ref. 16:p. 200]

Before continuing on with the discussion, we must make a couple of basic assumptions. First, it is assumed that $(d_3 - d_1) > -d_2$. This means that the buyer gains more by inspecting if the seller decides to cheat. Put another way, it is assumed that $(d_2 + d_3) > d_1$. These assumptions now allow us to develop a mathematical model which will relate the probabilities associated with the seller cheating, and the buyer inspecting, to the costs involved.[1]

Clearly, the safest strategy for the seller to take would be **Don't Cheat.** No matter which option the buyer chooses the seller will be equally as well off. He need not waste any time or energy trying to guess which option the buyer will take and base his decision on this "best guess." On the other hand, the buyer's choice is not as clear-cut. His selection depends heavily upon which strategy he feels the seller may take. If he feels comfortable entering into an agreement with the seller whereby he doesn't inspect and the seller doesn't cheat he would be wise to do so. Agreements of this type would surely become cooperative agreements. Each player would need continued assurance of the trustworthiness of the other. This could only be maintained through direct lines of communication between the two.

The ability of the market structure to maintain the cooperative agreement depends primarily upon the selfish interests of the seller. Once he makes a conscious decision to deviate from the cooperative agreement, the system breaks down. When this happens, we lose the ability to accurately predict which course of action each of the players will take.

[1]The complete mathematical analysis will not be developed here. For a detailed discussion of the development of the probabilities of inspection by the buyer and cheating by the seller, the reader is directed to [Ref. 16:pp. 200-204].

The alternative to such a cooperative agreement would be one of noncooperative equilibrium. Unfortunately there is no single option that satisfies this condition. Neither player has a strategy that, if selected, will provide him with the best payoff no matter which strategy his opponent selects. Therefore, the only noncooperative equilibrium is a mixed solution. Under equilibrium conditions the seller will cheat with some positive probability and he will be successful also with some positive probability.

Following through the model developed by Telser, [Ref. 16] he arrives at the following two conclusions based upon the assumption that the probabilities associated with the selection of either strategy by each of the players are equal. First, the expected return to the buyer boils down to an equation equal to the cost of inspections times the probability of inspecting and it will always be a negative amount (since the payoff associated with inspecting is a negative value). Second, the expected return to the seller will be zero [Ref. 16:p. 203]. The different values associated with each player results from the different payoffs to each under the four options presented by the matrix.

Contrary to what some may think, the equilibrium probability of inspecting is <u>not</u> affected by the cost of the inspections (d_1). Instead, it is determined by the ratio of $d_2/(d_2 + d_3)$. Refering back to one of our original assumptions, it should be clear that this ratio will always be greater than one. On the other hand, the probability of cheating <u>is</u> dependent upon the cost of inspections (as well as the amount of the penalty) as determined by the following ratio, $d_1/(d_2 + d_3)$. Once again, based upon our previous assumptions, this value will always be less than one.

The previous ratio provides us with the focal points to be used if we wish to reduce the probability of cheating. Of the three variables which make up the formula for determing this probability d_1 and d_3 are the only ones that can be effectively altered. Therefore we must focus our attention on either lowering the cost of inspection or raising the penalty in order to adequately reduce the probability of the seller cheating through the sale of counterfeit fasteners.

Baring the existence of collusion (which would require third party enforcement) between the two parties, it will be very difficult to determine which of the noncooperative solutions will be the equilibrium solution. There will always be a positive probability of cheating by the seller and discovery, through inspections, by the buyer. The best we can hope for is to reduce the probability of cheating to an acceptable level. The extreme case would be where the inspections are performed at no cost to the buyer and sellers caught cheating would be put to death. This would reduce the probability of cheating to near zero. Since authorizing of the death penalty in such cases is highly unlikely, in his mathematical model, Telser [Ref. 16] shows that reducing the cost of inspection is a more effective deterrent than raising the amount of the penalty. [Ref. 16:p. 203]

After careful review of the various options available to each party, the results are somewhat inconclusive and the prospects for a self-enforcing cooperative agreement are rather dim. Whether the seller chooses the cooperative agreement or decides to operate under the mixed noncooperative equilibrium scenario the end result is the same. His long-term return would be zero. Unfortunately, the buyer is not quite as fortunate. He would get zero under the cooperative agreement or $-d_2$ should the seller decide to violate the agreement (the $-d_2$ return results from the fact that the buyer does not inspect under the cooperative agreement). On the other hand, if the buyer operates under the noncooperative equilibrium scenario he will receive $-d_1$ times the probability of inspection. With these facts in mind, there is no chance that a self-enforcing agreement will work. In order for the cooperative agreement to succeed, each party must have a way to ensure cooperation by the other. [Ref. 16:p. 204]

The best the buyer can hope for is to keep the seller in line by inspecting some of the time. If he does catch the seller cheating, by trying to pass off nonconforming fasteners, he must have the ability to punish him through the assessment of appropriate penalties.

The current fastener situation is made even more complex when one considers the number of intermediaries or individual players involved. Referring once again to Figure 4, the marketing system currently in place for the foreign supplied fasteners is the one shown at the top. There are three separate buyer-seller transactions as the fasteners make there way from manufacturer to end-user. At each transaction point the Prizzi's Honor scenario previously discussed can be acted out. As each player attempts to out-guess his opponent and derive his most beneficial selection the number of combinations increases exponentially. The options become a little more manageable if one assumes that a certain amount of collusion exists between some of the players. Based upon recent reports and investigations, it appears that one can assume, with a fairly high degree of certainty, that collusion exists between the manufacturers and importers and it may possibly exist between the importers and the distributor/ vendor.

b. Summary

The non-zero sum game has provided us the tool with which to attack the counterfeit/nonconforming fastener issue. We must develop a way in which the parties directly involved in the fastener industry are able to monitor the system for compliance and bring pressure to bear upon those participants who attempt to improve their own position at the expense of others. In the following chapter, recommendations will be made on how this can be accomplished through the use of agencies already in place.

IV. CONCLUSION

A. SUMMARY

The issue of nonconforming, substandard, or counterfeit threaded fasteners has gained increased attention over the past ten years. This increased notoriety is primarily due to the large number of nonconforming fasteners currently being found within the marketplace. The percentage appears to be steadily increasing with no turn-around in sight.

Overseas manufacturers apparently are the only ones currently providing the nonconforming fasteners. Countries such as Korea, Taiwan, Japan, and Poland are the principal sources. The parts are brought into the U.S. market by importers acting as agents for various distributors and vendors. Once they enter the marketplace they are extremely difficult to detect. Unfortunately, they aren't of a different color or glow in the dark. On the contrary, from all outside appearances, they look just like any other nut or bolt. The only way users are able to identify the nonconforming components is by employing one of several test procedures developed specifically for this purpose--none of which are inexpensive to operate.

Because of the potential seriousness of the problem, it has drawn a significant amount of attention from both government and private agencies. Each of these has conducted its own independent investigations into the problem but they have all arrived at the same basic conclusion. Unless we eliminate the number of nonconforming fasteners currently entering the market place we run the risk of seriously impacting the integrity of ALL U.S. industries.

The focus of this report was what impact, if any, these nonconforming fasteners have had on the construction industry. Research has lead to the conclusion that construction has not been severely hampered by the present situation. Persons involved in the construction industry have indicated an awareness of the problem, and are perhaps being a little more cautious in their procurement practices, but the economic losses have been minimal. In most cases the costs have been so small that firms were able to easily absorb them into overhead expenditures.

Previous studies done on the effects these fasteners have had on manufacturing related firms have uncovered a more significant problem. Nonconforming fasteners have managed to infiltrate the supply systems of manufacturers of all types of equipment. This includes everything from cars and aircraft engines to the M-1 Tank. Inspections and audits conducted at government supply centers have uncovered millions of dollars worth of nonconforming parts and components. In some cases, the occurrence of these parts has limited the ability of units to perform their primary mission. [Ref. 18]

How then does one go about eliminating a problem that, if left unchecked, could have serious and far reaching repercussions? Discussions in the previous chapter indicated that several proposals are being developed in an attempt to stem the tide of counterfeit fasteners. The first one involved modifications to the current marketing structure to eliminate the middlemen and thereby make tracking and identification of the components easier. Analysis of this proposal showed that while it was not without merit, it would involve other economic costs associated with lost efficiency and therefore might not be a viable solution.

The second solution centered around various forms of government intervention. One dealt with government agencies acting as information data bases (GIDEP). Other government agencies, as well as outside contractors involved in government projects, are allowed free access to this information. One element contained within this data base provides a list of distributors and/or vendors which have been caught supplying nonconforming fasteners. The system attempts to force these suppliers out of business by making their actions known to the buying public. Unfortunately, the information contained in the GIDEP data base does not get widespread distribution.

Congress has also attempted to solve the problem at the highest levels of government through the passage of various laws. Bills such as H.R. 336 the "Standardization of

Measurement Act" and H.R. 777 the "Fastener Quality Assurance Act" were two initial attempts by Congress to resolve the counterfeit fastener issue. Both appeared to be lacking in substance and clout. The bill currently under consideration, H.R. 3000 the "Fastener Quality Act," is by far the most comprehensive attack on the counterfeit fastener issue and would probably go a long way towards solving the problem. However, as previously stated, government intervention may not be the optimum solution to the problem. Government bureaucracies such as the one envisioned in this bill tend to impose abnormally high costs on the general public.

The only way in which we can reach a comprehensive long-term solution is to gain the cooperation of the parties most directly involved with the problem. A system needs to be developed whereby the agreements reached between buyer and seller are easily enforceable and the costs associated with breaking from the agreement are significant. Monitoring and control needs to be simplistic and self-supporting.

B. RECOMMENDATIONS

Any long-term solution to the problem must involve those firms and/or organizations <u>directly involved</u> in fastener distribution within the United States. Dependence upon agencies or governments outside of our own territorial jurisdiction would be fruitless.

Who then are these players? The two obvious ones are the distributors and vendors of fasteners as well as the end-users, or buyers, of the fasteners. Of a less obvious nature are the agencies and organizations which associate themselves with the fastener industry. Since 99 percent of the risk associated with the use of these counterfeits falls upon the end-user, it would not be in their best interest to knowingly use the nonconforming products. Policing or monitoring of their operations is therefore not necessary. We must focus our attention on controlling the actions of the seller, because he currently has the least to lose and the most to gain. How then do we go about shifting the balance of power in favor of the buyer?

The conclusions arrived at under the Prizzi's Honor scenario discussed in Chapter III provide the key. Using the available mathematical models we were able to show that the only real deterrents to cheating are to reduce the cost of inspection to the buyer or increase the penalty assessable to the seller. Organizations such as the Industrial Fastener Institute are in the best possible position to accomplish both.

Up to now, the IFI has only acted as an information pool to keep its constituents informed of on-going issues relevant to the fastener industry. Suppose they began to take on a more active role. They have all the resources necessary to develop an "Association of Fastener Suppliers." This organization could establish a network of approved, or "licensed," fastener suppliers. The association would be responsible for frequent random sampling of its members output to insure compliance with its rules and regulations. By conducting product testing on a large scale basis at suppliers, importers, or major U.S. finishers, they would reduce the cost of individual inspections through economies of scale. They would also be able to guarantee the reliability or credibility of the testing laboratory thereby eliminating the possibility of false testing documentation. The costs associated with establishing and maintaining such an organization could be collected through annual membership fees from its members. Once established and fully functional, buyers would then choose to conduct business with association members. This would provide them with the highest assurance possible that the components they are receiving conform to the specifications as labeled.

Initially, one may argue that the only thing this accomplishes is to shift the cost of inspections from the buyer to the seller. This is not necessarily true. The ultimate result would more than likely be a slight overall increase in the cost of the fasteners to the buyer resulting in a cooperative agreement at a higher base amount. The buyer is able to receive the benefits of reduced inspection costs associated with the pooling of resources and information. Each buyer is no longer required to perform his own inspections of each and every supplier he deals with. The supplier gains through reduced competition. The rational buyer is sure to purchase his parts from members of the association.

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