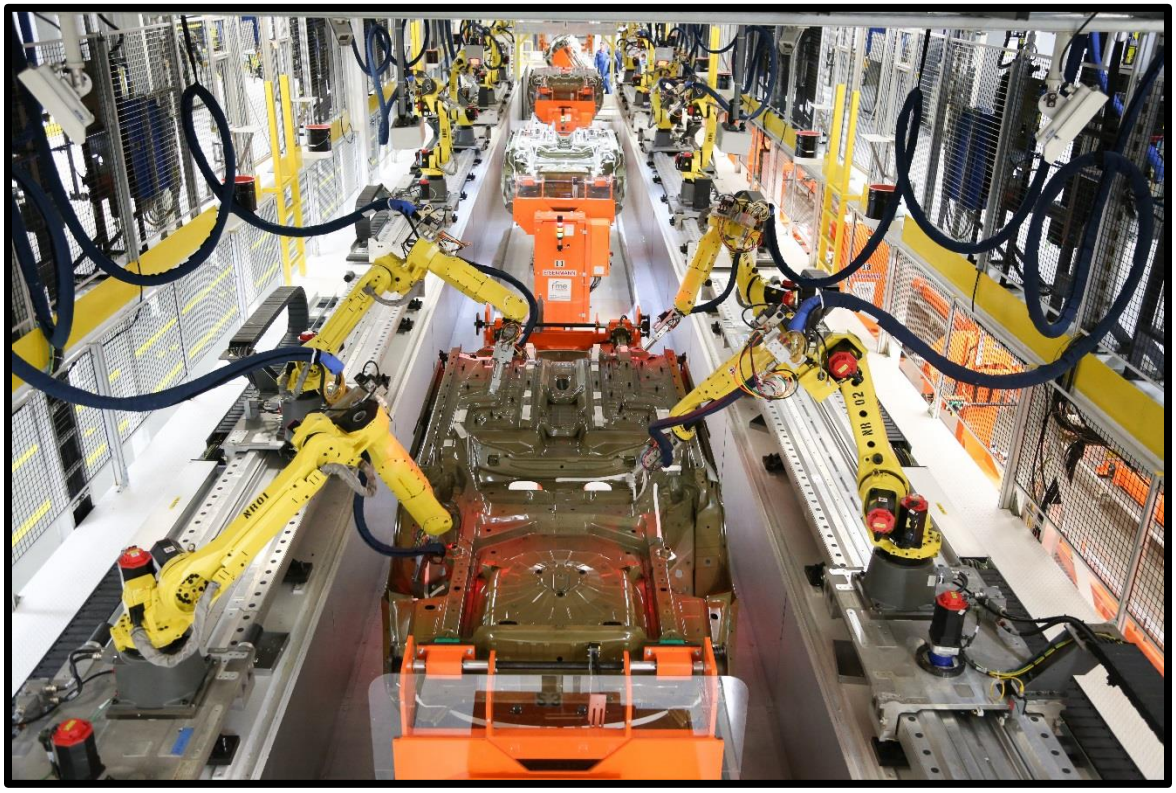
NIST Special Publication 1601

Tracking Industry Operations Activity
A Case Study of US Automotive Manufacturing

Douglas S. Thomas
Anand M. Kandaswamy



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Applied Economics Office
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Abstract

Private firms, driven by competition, frequently achieve advances in efficiency on their own accord; however, there are often barriers to advancement that surpass the ability of any single firm. Additionally, competition, lack of communication, and other factors can prevent the collaborative efforts necessary to overcome such barriers. It is in these types of situations that publicly-funded research efforts are often necessary for advancing industry efficiency. Unfortunately, there are numerous factors affecting efficiency and only a limited number of them can be identified. The result is that researchers must examine areas of manufacturing that consume high levels of resources in order to identify change agent efforts that have a high return on investment. To identify high resource areas it is necessary to have an inventory and model of resource consumption. This report identifies data on manufacturing activity and provides a model for tracking operations activity. The method is then illustrated in the automotive manufacturing industry.

There are two potential approaches to track resource consumption: a top down approach and a bottom up approach. Data at the broadest level is readily available, but as one moves towards more and more detail, data becomes scarcer. For this reason a top down approach is developed. Data for a bottom up approach is briefly discussed; however, this approach is left for future research due to data limitations. The top down method is applied to the automotive manufacturing industry as a case study, which includes a review of automotive manufacturing. This approach provides a more comprehensive exploration of data for tracking industry operations activity at all levels of detail. The top down analysis uses input-output analysis combined with other industry data to estimate industry operations activity. The aggregated dataset layout is a 1238 by 397 matrix resulting in over 490 000 information points on the US economy with over 290 000 being related to manufacturing. That is, the data provides over 490 000 categories of information covering compensation costs, taxes, gross operating surplus, labor hours, production time, environmental impacts, natural resource use, energy consumption by end use (e.g., heating/cooling and production processes), and building capital. Compensation and other labor related activities are broken into over 800 different occupations for each industry. Industry data is broken into over 300 NAICS codes categories for each industry. Environmental and natural resource consumption is broken into 12 TRACI categories. This model incorporates the resources used in US manufacturing and its US based supply chain.

Keywords: supply chain; value chain; manufacturing; input output; automotive manufacturing; manufacturing

Preface

This study was conducted by the Applied Economics Office in the Engineering Laboratory at the National Institute of Standards and Technology. The study provides a model for tracking manufacturing industry operations activity and illustrates the use of the model in the automotive industry.

Disclaimer

Certain trade names and company products are mentioned in the text in order to adequately specify the technical procedures and equipment used. In no case does such identification imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the products are necessarily the best available for the purpose.

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At the Paint Shop in Chrysler Group's Sterling Heights (Mich.) Assembly Plant, a 2015 Chrysler 200 moves through the Underbody Sealing and Underbody Coating station, flipping the vehicle body completely upside down to seal all appropriate seams and compartments. (2014). This image was used in accordance with Fiat Chrysler Automobile's editorial use policy.

Acknowledgements

The authors wish to thank all those who contributed so many excellent ideas and suggestions for this report. Special appreciation is extended to Simon Frechette, Katherine Morris, and Dr. Vijay Srinivasan of the Engineering Laboratory's Systems Integration Division for their technical guidance, suggestions, and support. Special appreciation is also extended to Dr. Stanley Gilbert, Dr. Robert Chapman, and Paul Rothfeld of the Engineering Laboratory's Applied Economics Office for their thorough reviews and many insights. The authors also wish to thank Dr. Nicos Martys, of the Materials and Structural Systems Division for his review.

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Reading tables: Tables frequently have colored bars (red, blue, or orange). These bars provide comparisons between other figures in the table that are shown in the same color.

List of Acronyms

AHP: Analytical Hierarchical Process
ASM: Annual Survey of Manufactures
BEA: Bureau of Economic Analysis
BEES: Building for Environmental and Economic Sustainability
CAR: Center for Automotive Research
CTU: Comparative Toxicity Unit
CTUe: Comparative Toxicity Unit for Ecotoxicity
CTUHcan: Comparative Toxicity Unit for Human health related to Cancer
CTUHnoncan: Comparative Toxicity Unit for Human health non related to cancer
eq: Equivalent
FAF: Freight Analysis Framework
HH_can: Human Health issues related to cancer
HH_noncan: Human Health issues not related to cancer
HVAC: Heating, Ventilation, and Air Conditioning
IO: Input-Output
LCA: Life Cycle Assessments
MECS: Manufacturing Energy Consumption Survey
NAICS: North American Industry Classification System
NIST: National Institute of Standards and Technology
OES: Occupational Employment Statistics
QFD: Quality Function Deployment
SCTG: Standard Classification of Transported Goods
SIC: Standard Industrial Classification System
SOC: Standard Occupational Classification System
TRACI: Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts

1 Introduction

1.1 Background

One justification for supporting economic growth through publicly-funded research is based on what economists call "market failures." [1] These are instances where the market outcome or allocation of goods and services is not Pareto efficient. This occurs when it is possible to make one person better off without making another person worse off. Unfortunately, in a world of scarce resources, there are limited public funds for addressing market failures; therefore, the efforts that have the greatest impact per dollar of public investment are, typically, prioritized over those with a lower impact per dollar. Additionally, there are many market failures in the economy; however, there are limited funds for identifying where and why these market failures are occurring. Thus, only a portion of the market failures are being identified by researchers. Given that researchers can only identify and analyze a portion of the total market failures, it is necessary to search for market failures in areas that are likely to have a high return on investment. The focus of this report is on identifying and analyzing those factors that affect manufacturing efficiency.

An inventory and model of resource consumption in manufacturing will help identify high resource consumption areas or hotspots. Change agents, which invest in advancing the current state of manufacturing, might then search for non-pareto efficient circumstances within these hotspots. Unfortunately, the data required for such an inventory and model is disjointed. Therefore, it is necessary to assemble the data and develop a model of resource utilization for identifying potential public investments.

NIST, a publicly-funded research organization, "promote[s] US innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life."[2] A significant focus for NIST is in advancing innovation and industrial competitiveness by improving efficiency in manufacturing. Few private entities have the objectives that a publicly-funded research organization maintains. Additionally, some firms may have a limited perspective, as each firm's situation is unique from the others. The result is that there are few research reports on the data or inventory of resources needed to identify industry-wide hotspots in resource consumption.

1.2 Purpose

This report identifies and reviews data on manufacturing activity and provides a method for developing a model of industry operations activity, which documents the resources consumed. The method is then illustrated in the automotive manufacturing industry. Data

[1] Tassey, Gregory. Methods for Assessing the Economic Impacts of Government R&D. Planning Report 03-1. <http://www.nist.gov/director/planning/upload/report03-1.pdf>

[2] National Institute of Standards and Technology. "NIST General Information." <http://www.nist.gov/public_affairs/general_information.cfm>

at the broadest level is readily available, but as one moves towards more and more detail, data becomes scarcer. For this reason, a top down approach is described and data for a bottom up approach is briefly explored. Additionally, there is a review of automotive manufacturing, specifically. The top down data model will facilitate identifying areas of manufacturing that have a high level of resource consumption. Future research might then examine these areas for non-Pareto efficient circumstances. Data for a bottom up approach would facilitate identifying details on resource consumption; however, the collection and analysis of this data is beyond the scope of this report.

1.3 Scope and Approach

This report takes principles found in operations management and applies them at the industry level. Operations management refers to the business practices that pursue the highest level of efficiency within an organization. It is concerned with converting inputs into outputs as efficiently as possible. Typically, it refers to management at the organization or firm level. This report identifies a method for tracking industry operations activity and illustrates this method using a case study of automotive manufacturing. Resource consumption is often measured in dollars, especially at the industry level; however, this unit can mask the source of the dollars being consumed and misdirect efforts to improve efficiency. For example, labor costs are a function of time, human effort, and rates of compensation. High labor costs may be the result of large amounts of labor or, alternatively, it could be high rates of compensation. The purpose of tracking industry operations activity in this report is to identify areas of manufacturing that have a high level of resource consumption so that future research might reduce this consumption. The report not only examines the cost of production, it also examines the source of those costs. Negative externalities are another reason resource use needs to be tracked beyond dollar representations. Negative externalities, such as environmental impacts and natural resource consumption, are not well represented in terms of dollars.

Manufactured goods are produced to serve some purpose. A change agent, such as NIST, can facilitate serving this purpose in a more efficient manner or facilitate serving new or improved purposes. Therefore, in examining manufacturing there are the costs or resources required to produce and use a product and there are the benefits or activities that the product facilitates. The costs and benefits of the products are distributed over a range of stakeholders, including the owners, employees, consumers, and even the general public. In a perfect world all of the costs and benefits would be assembled and categorized together; however, the data is disjointed and has incomplete coverage. For these reasons, this report reviews data on the resources used in production. More specifically, these include natural resources, employee hours, and environmental impacts. Additionally, production time, transport time, and inventory time are also examined.

This report first discusses change agents, stakeholders, and the geographic scope of this report in Section 2. This section begins with a discussion on efficiency followed by a discussion on change agents and the stakeholders they affect. It also lays out the geographic scope and the standard categorization of data. Section 3 provides a discussion on top down and bottom up data. It presents the formats for the various top down datasets and discusses the scarcity of bottom up data. Section 4 presents a top down method that

utilizes an input-output model combined with the various datasets on resource utilization. Section **Error! Reference source not found.** illustrates the method for the automotive ndustry. It begins with an overview of automotive manufacturing, as represented in the literature and transitions to discussing a characterization of the industry with the input-output model presented in Section 4. The final section is a summary of the report.

2 Change Agent Activities, Stakeholders, and Geographic Scope

Economic data, typically, focuses on areas encompassed by a political boundary and is relevant to a subset of stakeholders. This section discusses the motivation for this report along with its geographic scope and stakeholders applicable to this report.

2.1 Efficiency and Market Failures

As stated previously, the justification for supporting economic growth through publicly funded research is what economists call "market failures." [3] These are instances where the market outcome or allocation of goods and services is not Pareto efficient; that is, it is possible to make one person better off without making another person worse off. Pareto efficiency is a type of allocative efficiency, which is defined as the optimal distribution of goods and services. Pareto efficiency is related to both consumer and producer oriented efficiencies, as illustrated in Figure 2-1. Productive efficiency relates to maximizing output for the given inputs. It is what engineers are, typically, referring to when discussing efficiency. Consumer oriented efficiency issues relate to maximizing utility. It includes consumer choice and combinations of goods produced. A market failure can occur when one of the types of efficiency in Figure 2-1 is not fulfilled by the market interactions of consumers and producers. NIST is an entity that focuses on "measurement science, standards, and technology," which, in some ways, is production oriented; however, consumer issues are being addressed as well. The data and models in this report focus on issues related to productive efficiency, as it focuses on the resources consumed in production. Future research may move toward consumer oriented issues by tracking the resources used to fulfill consumer preferences.

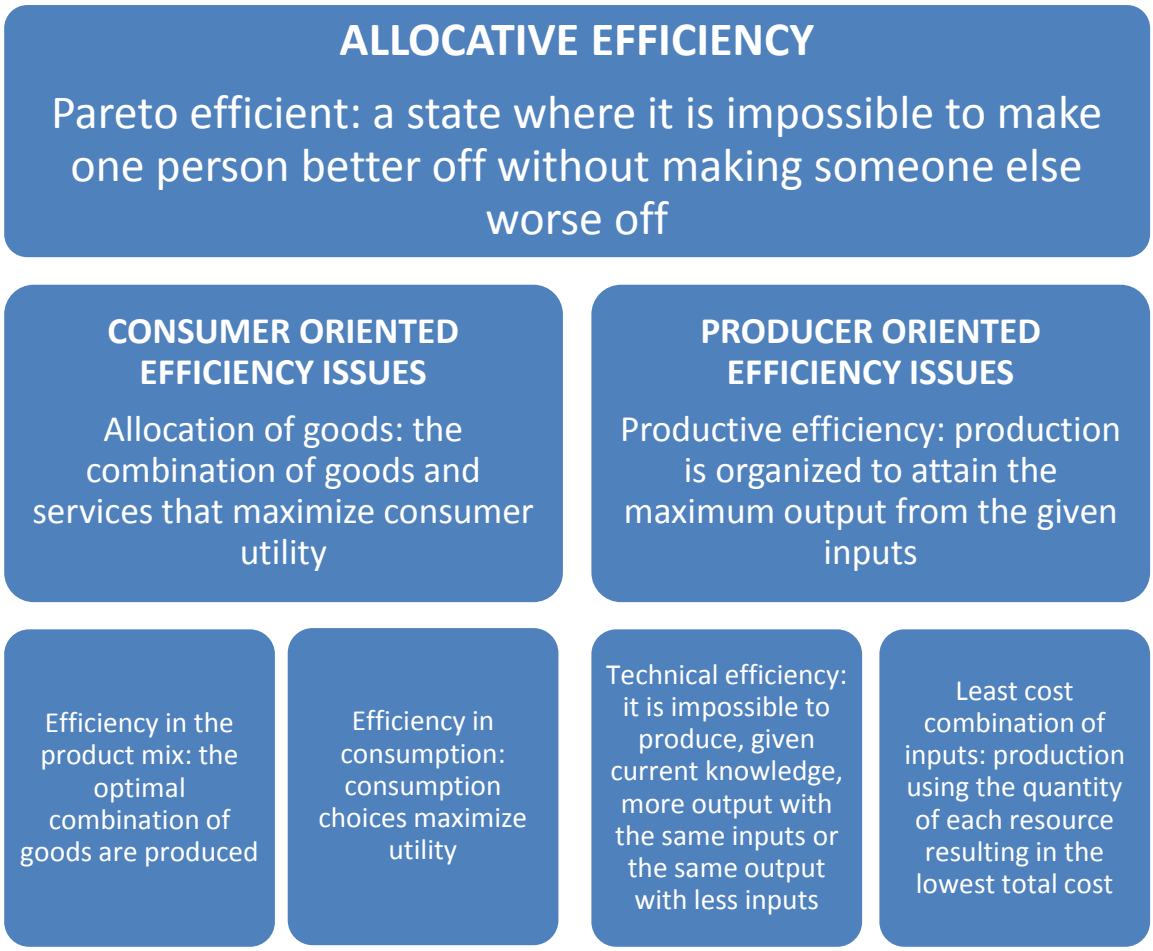
When tracking efficiency, there are inputs and outputs being examined, but there are significant data challenges in tracking consumer utility and the physical items produced (i.e., the outputs). For this reason, this report focuses on tracking inputs as this is likely to reveal high return-on-investment areas for addressing non-Pareto efficient circumstances.

2.2 Change Agents

Generally, change agents such as NIST want to maximize their impact for the amount of resources allotted to them; that is, they want the "biggest bang for the buck." Investment in any particular change agent effort, traditionally, has decreasing returns to scale; that is, every additional dollar of investment has a little less impact than the previous dollar. Since a change agent wants to maximize their impact, it would want to allocate its funding in projects such that each dollar of investment has the maximum return possible.

[3] Tassey, Gregory. Methods for Assessing the Economic Impacts of Government R&D. Planning Report 03-1. <http://www.nist.gov/director/planning/upload/report03-1.pdf>

Figure 2-1: Definitions of Efficiency



Note that this figure is not suggesting that if all the subcategories are fulfilled then the parent category is necessarily fulfilled.
Definitions adapted from Barr, Nicholas. 2012. Economics of the Welfare State. 5th Edition. (Oxford University Press, Oxford, UK: 2012) 43-44. and Besanko, David and Ronald R. Braeutigam. Microeconomics. 2nd edition. (John Wiley & Sons, Hoboken, NJ: 2005). And Navarro, Peter. "The Power of Microeconomics: Economic Principles in the Real World." Coursera. Paul Merage School of Business, University of California at Irving. <https://www.coursera.org/learn/principles-of-microeconomics>

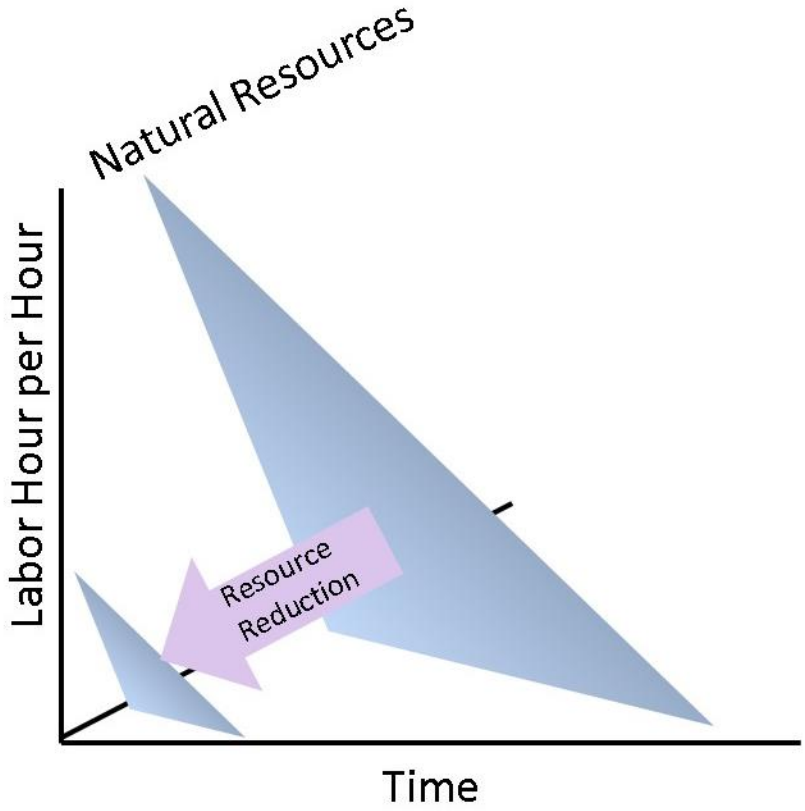
It is important to note that not all of the costs and benefits are able to be measured. Additionally, investments are often complex; therefore, identifying the optimal use of funding can be rather problematic. Due to scarcity, there are also limited funds for identifying where market failures are occurring; thus, all the potential efforts that would be examined are not able to be identified. Therefore, it is necessary to maximize the probability of identifying those market failures and investments that have the highest return. This report develops an inventory and a model of resources used in manufacturing that can be used to increase the probability of identifying those change agent investments that have a high return.

To track resources in manufacturing there is a need to categorize them. At the basic level, the factors of production are, typically, considered to be land (i.e., natural resources), labor, capital, and entrepreneurship; however, capital includes machinery and tools, which themselves are made of land and labor. Additionally, a major element in the production of all goods and services is time, as illustrated in many operations management discussions. Therefore, one might consider the most basic elements of production to be land, labor, human capital, entrepreneurship, and time. The human capital and entrepreneurship utilized in producing manufactured goods are important, but these are complex issues that are not a focus of this report. The remaining items land, labor, and time constitute the primary cost elements for production. It is important to note that there is a tradeoff between time and labor (measured in labor hours per hour). For example, it takes one hundred people less time to build a house than it takes for one person to build a house. It is also important to note that there is also a tradeoff between time/labor and land (i.e., natural resources), as illustrated in the large triangular plane in Figure 2-2. For example, a machine can reduce both the time and the number of people needed for production, but utilizes more energy and natural resources.

The large triangular plane in Figure 2-2 represents possible combinations of land, labor, and time needed for producing a manufactured good. Moving anywhere along this plane is an alteration of resource use. This combination is, typically, determined by the least cost combination of inputs, as mentioned in Figure 2-1. A public change agent, however, might also consider the impact on natural resources and the environment, costs that are not borne by the producer. Replacing labor with machines, for example, increases the production per person but might decrease the production per unit of natural resource. A company can maximize profit by either altering resources (i.e., moving along the plane to the least cost combination of inputs) or by reducing the resources needed for production (i.e., moving the plane or improving technical efficiency). A public change agent that desires efficient and sustainable production would seek to reduce all three resources, pulling the triangular plane or some portion of it toward the origin as illustrated in the figure. Therefore, when examining the cost and benefits of a product or process from a societal perspective, it becomes apparent that one needs to measure land, labor, and time needed for production in order to understand potential areas of resource reduction.

In addition to resources consumed in production, manufactured goods are produced to serve a designated purpose. For example, automobiles transport objects and people; cell phones facilitate communication; and monitors display information. Each item produced is designed for some purpose. In the process of fulfilling this purpose more resources are often expended in the form of land, labor, and time, which are related to consumer-oriented efficiencies. Additionally, a product with a short life span results in more resources being expended to reproduce the product and the disposal of the old product may also consume resources. The consumption of these resources is important, but due to data constraints is left as a focus of future research.

Figure 2-2: Time, Labor, and Natural Resources Needed to Produce a Manufactured Product



Source: Thomas, Douglas S. Costs and Cost Effectiveness of Additive Manufacturing: A Literature Review. December 2014. NIST Special Publication 1176. <http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1176.pdf>

2.3 Stakeholders

Each of the costs and benefits affects different stakeholders, as seen in the brief list in Table 2-1. From this list, expenditures, hours, price, environment, and natural resources are examined directly or indirectly in this report. The other elements are important; however, data limitations and challenges make them targets for future research. As seen in Table 2-2, stakeholders may have a direct investment in manufacturing, such as industry owners and employees, or an indirect investment through supply chains or industry outputs. Each stakeholder is associated with a primary form of investment. For

Table 2-1: Abridged List of Stakeholders

Stakeholders	Costs	Benefits
Owners/Investors	Expenditures	Profit
Employees	Hours/Safety/Health	Compensation
Consumers	Price/Cost of Use	Utility
General Public	Environment/Natural Resources	Economic Well Being

Table 2-2: Manufacturing Stakeholders

Stakeholders	Affiliation	Primary Investment	Expected Return
Owners	Private Producers	Land, Capital Goods, and Financial Capital	Profit From Sales
Employees (manufacturing industry and suppliers)	Laborers	Labor *and Safety*	Income
Resellers	Private Distributer	Land, Capital Goods, and Labor	Profit From Markup
Retailers	Private Distributer	Land, Capital Goods, and Labor	Profit From Markup
Wholesalers	Private Distributer	Land, Capital Goods, and Labor	Profit From Markup
Standards and Codes Organizations	Public/Private Interest	Labor and Intellectual Property	*Economic Success*
Transportation and Warehousing	Support Service	Land, Capital Goods, and Labor	Profit From Fees
Air Transportation Providers	Transportation	Land, Capital Goods, and Labor	Profit From Fees
Ground Transportation Providers	Transportation	Land, Capital Goods, and Labor	Profit From Fees
Warehousing and Storage Providers	Storage Facility	Land and Capital Goods	Profit From Fees
Professional Societies	Public/Private Support Services	Labor *and Intellectual Property*	*Economic Success* and Profit from Fees
Finance Services	Insurance and Finance	Financial Capital	Profit From Fees
Insurance Providers	Insurance	Financial Capital	Profit From Fees
Health and Medical Insurance Providers	Insurance	Financial Capital	Profit From Fees
Financiers	Financier	Financial Capital	Capital Gains
Public Vested Interests	Public	Labor and Financial Capital	*Economic Success*
Policy Makers	Public	Labor and Financial Capital	*Economic Success*
Tax Payers/Public	Public	Financial Capital and Natural Resources	*Economic Success*
Industry Suppliers	Public/Private Suppliers	Land, Capital Goods, and Labor	Profit
Mining Material Suppliers	Private Suppliers	Land, Capital Goods, and Labor	Profit From Sales
Agriculture Product Suppliers	Private Suppliers	Land, Capital Goods, and Labor	Profit From Sales
Electric Utility Suppliers	Private Suppliers	Land, Capital Goods, and Labor	Profit From Sales
Water Utility Suppliers	Public/Private Suppliers	Land, Capital Goods, and Labor	Profit From Sales
Natural Gas Suppliers	Private Suppliers	Land, Capital Goods, and Labor	Profit From Sales
Facility Construction Providers	Private Suppliers	Land, Capital Goods, and Labor	Profit From Sales
Maintenance and Repair Providers	Private Suppliers	Land, Capital Goods, and Labor	Profit From Sales
Communication Services Providers	Private Support Services	Land, Capital Goods, and Labor	Profit From Fees
Other Fuel Suppliers	Private Suppliers	Land, Capital Goods, and Labor	Profit From Sales
Refuse Removal Service Providers	Private Support Services	Land, Capital Goods, and Labor	Profit From Fees
Professional Services	Public/Private Support Services	Land, Capital Goods, Labor, *and Intellectual Property*	Profit From Fees
Legal Service Providers	Public/Private Support Services	Labor	Profit From Fees
Information Service Providers	Private Support Services	Land, Capital Goods, and Labor	Profit From Fees
Research Organizations	Public/Private Suppliers	Labor *and Intellectual Property*	Profit From Fees
Accounting Service Providers	Private Support Services	Labor	Profit From Fees
Engineering Service Providers	Private Support Services	Labor *and Intellectual Property*	Profit From Fees
Computer Service Providers	Private Support Services	Labor	Profit From Fees
Scientific and Technical Service Providers	Private Support Services	Labor *and Intellectual Property*	Profit From Fees
Advertisers	Private Support Services	Labor *and Intellectual Property*	Profit From Fees
Other Professional Services	Private Support Services	Labor *and Intellectual Property*	Profit From Fees
Consumers/End User	End User	*Product Purchasing Price and Cost of use*	*Final Product Utilization*

Source: Adapted from Thomas, Douglas S. March 2012. The Current State and Recent Trends in Manufacturing. Special Publication 1129. <http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1142.pdf>

example, employees invest their labor while owners invest land and capital. Owners may have significant investments of labor and/or intellectual property as well, as seen in Table 2-2. The items shown in red in the table are items that are not directly examined in this report, due to data limitations.

Each stakeholder has invested these items with the expectation of receiving compensation or a return on investment. Employees, for instance, expect to be compensated for their labor and owners expect to receive a profit. There are eight different categories of assets used in Table 2-2 that can be utilized in the industry: financial capital, capital goods, land, labor, intellectual property, safety, cost of use, and the end users purchasing price. In this table, stakeholders are defined by activities where a company or individual might be considered more than one stakeholder. For instance, a mining company might also be involved in identifying where raw materials are located. In this instance they would be a mining material supplier and a scientific and technical service provider.

The expected returns from the industry include profits from sales, markup, or fees; income; economic success; capital gains; and utility from the final use of the product. The expected returns for each stakeholder are categorized in Table 2-2.

Summary of Primary Investments

Land	Naturally-occurring goods such as water, air, soil, mineral, and flora used in the production of products (i.e., the totality of goods or services that a company makes available).
Labor	Human effort used in production, which includes technical and marketing expertise.
Capital Goods	Human made goods used in the production of products.
Financial Capital	Funds provided by investors to purchase capital goods for production of products.
Intellectual Property	Ideas, trademarks, copyrights, trade secrets, and patents used to produce products
Purchasing Price	Market value of products sold
Safety	Safety and health that a worker sacrifices for production
Cost of Use	Resources that are consumed by the use a manufactured product

2.4 Geographic Scope and Imported Goods and Services

Many change agents are concerned with a certain group of people or organizations. Since NIST is concerned with "US innovation and competitiveness," this report focuses on activities within the national borders. In a world of globalization, this effort is somewhat challenging, as some of the parts and materials being used in US manufacturing activities are imported. NIST Technical Note 1810 examined the proportion of the US

Summary of Expected Returns

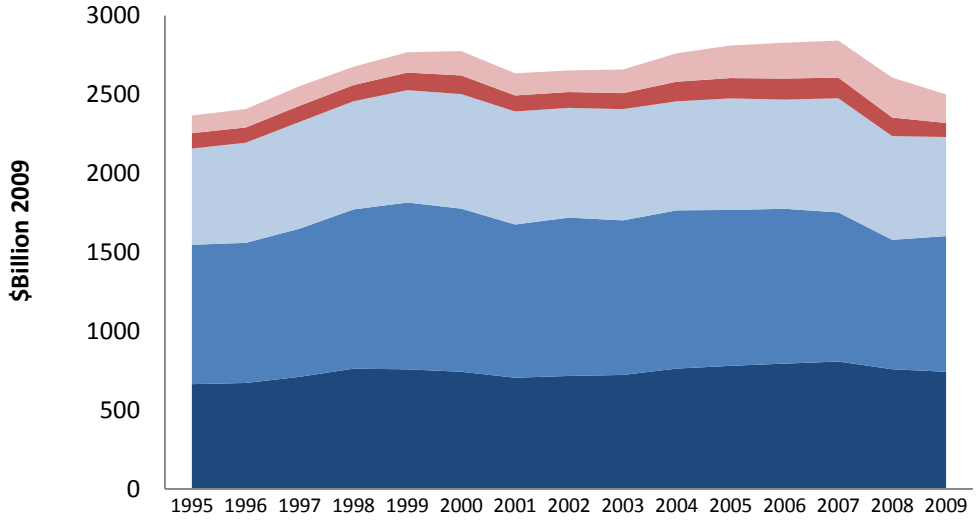
Profit from Sales	The financial benefit realized when revenues exceed costs and taxes for a product.
Capital Gains	An increase in the value of a capital asset
Income	Compensation for an individual's service or labor
Profit from Markup	*T*he difference between the cost of a product and its selling price.
Economic Success	A constant and suitable magnitude of production resulting in competitive benefits (profits, capital gains, income, and product utilization) for an industry's stakeholders.
Profit from Fees	The financial benefit realized when revenues exceed costs and taxes for a service.
Final Product Utilization	The utility gained from the end user of a product.

manufacturing supply chain that is imported. The value added for the U.S. manufacturing industry and its supply chain is presented in Figure 2-3. The values at the top, shown in red, represent value added that is imported to the U.S. for use by the manufacturing industry. The top value, shown in a lighter red, represents intermediate imported non-manufactured goods and services, such as raw materials from mining. The second one, shown in a darker red, represents intermediate imported manufactured goods used by the U.S. manufacturing industry. Domestic U.S. manufacturing activity is shown in three shades of blue. The light blue represents intermediate non-manufactured goods and services, such as agricultural products or finance products, produced in the U.S. and used by the U.S. manufacturing industry. The darker blue represents intermediate manufactured products used by the U.S. manufacturing industry; for example, a bolt used to assemble a car. The bottom value, shown in a dark blue, represents final products manufactured in the U.S. As can be seen in the figure, the imported values are a relatively small percentage of the total activity. In terms of 2009 imported supply chain value added used by a nation's manufacturing industry, the U.S. imported 10.8 % of its supply chain. These imports have environmental impacts, require natural resources, and utilize labor; thus, they are important in regards to a firm's production. Since our focus is on US innovation and industrial competitiveness, the imported goods and services are outside of the scope of this report.

2.5 Standard Data Categorization

A number of datasets are used in developing an inventory and model of industry operations activities. Bringing these datasets together requires standard categories of classification. Although standard categorization seems mundane, it is critical to tracking

Figure 2-3: US Manufacturing Supply Chain Value Added



	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Foreign Intermediate Non-manufacturing	111	117	124	116	129	155	140	137	150	180	206	227	235	253	181
Foreign Intermediate Manufacturing	98	97	102	103	111	118	101	100	101	124	129	133	131	118	89
U.S. Intermediate Non-manufacturing	609	635	677	686	712	726	717	696	705	691	707	692	723	657	628
U.S. Intermediate Manufacturing	883	888	939	1009	1057	1034	971	1003	980	1003	988	981	945	820	860
U.S. Final Product	664	671	711	762	758	742	705	716	722	763	780	794	807	758	742

Source: Thomas, Douglas S. The US Manufacturing Value Chain: An International Perspective. February 2014. NIST Technical Note 1810. <http://www.nist.gov/customcf/get_pdf.cfm?pub_id=914022>

resources. The standardized classification systems used in this report include

- North American Industry Classification System (NAICS): a standard used by Federal statistical agencies to classify business establishments in the U.S.
- Standard Occupational Classification System (SOC): a standard used in the U.S. to classify workers into occupational categories for collecting and distributing data on employees
- Standard Classification of Transported Goods: a standard in the U.S. to classify transported commodities.
- Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI): a set of sustainability metrics for measuring environmental impacts and natural resource utilization

Each dataset incorporated into the model uses NAICS codes or is altered to fit to the codes, which allows the datasets to be compatible with each other. Some datasets may use just the NAICS codes while others use NAICS codes and another classification system together to form a data matrix.

2.5.1 The North American Industry Classification System (NAICS)

Domestic data tends to be in the North American Industry Classification System (NAICS). It is the standard used by Federal statistical agencies classifying business establishments in the U.S. NAICS was jointly developed by the U.S. Economic Classification Policy Committee, Statistics Canada, and Mexico's Instituto Nacional de

Estadística y Geografía and was adopted in 1997.[4] NAICS has several major categories each with subcategories. Historic data and some organizations continue to use the predecessor of NAICS, which is the Standard Industrial Classification system (SIC). NAICS codes are categorized at varying levels of detail. Table 2-3 presents the lowest level of detail, which is the two digit NAICS. There are 20 categories. Additional detail is added by adding additional digits; thus, three digits provides more detail than the two digit and the four digit provides more detail than the three digit. The maximum is six digits, as illustrated for automobile manufacturing (NAICS 336111) and light truck and utility manufacturing (NAICS 336112). Sometimes a two, three, four, or five digit code is followed by zeros, which do not represent categories. They are null or place holders. For example, the code 336000 represents NAICS 336.

2.5.2 Standard Occupational Classification System (SOC)

Federal statistical agencies classify workers into occupational categories for collecting and distributing data on employees. The 2010 version has 840 occupations. These are which are categorized into 23 major groups. Occupations with similar job duties, skills, categorized into 461 broad occupations, which are categorized into 97 minor groups, education, and/or training are grouped together. Similar to the NAICS codes, additional digits represent additional detail up to a maximum of six digits, as illustrated for SOC 514011 and SOC 514012 in Table 2-4, which presents the 23 major groups. The SOC classifies all occupations in which work is performed for pay or profit. It was first published in 1980, but was rarely utilized at that time. In 2000, it was revised and then

Table 2-3: North American Industry Classification System, Two Digit Codes

Sector	Description
11	Agriculture, Forestry, Fishing and Hunting
21	Mining, Quarrying, and Oil and Gas Extraction
22	Utilities
23	Construction
31-33	Manufacturing
336	*Transportation Equipment Manufacturing*
3361	*Motor Vehicle Manufacturing*
33611	*Automobile and Light Duty Motor Vehicle Manufacturing*
336111	*Automobile Manufacturing*
336112	*Light Truck and Utility Manufacturing*
42	Wholesale Trade
44-45	Retail Trade
48-49	Transportation and Warehousing
51	Information
52	Finance and Insurance
53	Real Estate and Rental and Leasing
54	Professional, Scientific, and Technical Services
55	Management of Companies and Enterprises
56	Administrative and Support and Waste Management and Remediation Services
61	Educational Services

[4] US Census Bureau. North American Industry Classification System. <http://www.census.gov/eos/www/naics/>

62	Health Care and Social Assistance
71	Arts, Entertainment, and Recreation
72	Accommodation and Food Services
81	Other Services (except Public Administration)
92	Public Administration

again revised in 2010. The Bureau of Labor Statistics now publishes occupation data based on this system.

2.5.3 Standard Classification of Transported Goods (SCTG)

The Census Bureau tracks the movement of goods in its Commodity Flow Survey and uses the Standard Classification of Transported Goods (SCTG) to group commodities together. In the 1990s, this system replaced its predecessor, the Standard Transportation Commodity Codes (STCC). The new SCTG codes are similar to NAICS in that there is varying levels of detail. The SCTG codes, however, have a maximum of only five digits, as illustrated for SCTG code 36101 and 36109 in Table 2-5. As seen in the table, two digit codes provide the broadest level of categorization. Additional digits are added for

Table 2-4: Standard Occupational Classification System, Two Digit Codes

Occupation Code	Occupation Name
11	Management Occupations
13	Business and Financial Operations Occupations
15	Computer and Mathematical Occupations
17	Architecture and Engineering Occupations
19	Life, Physical, and Social Science Occupations
21	Community and Social Service Occupations
23	Legal Occupations
25	Education, Training, and Library Occupations
27	Arts, Design, Entertainment, Sports, and Media Occupations
29	Healthcare Practitioners and Technical Occupations
31	Healthcare Support Occupations
33	Protective Service Occupations
35	Food Preparation and Serving Related Occupations
37	Building and Grounds Cleaning and Maintenance Occupations
39	Personal Care and Service Occupations
41	Sales and Related Occupations
43	Office and Administrative Support Occupations
45	Farming, Fishing, and Forestry Occupations
47	Construction and Extraction Occupations
49	Installation, Maintenance, and Repair Occupations
51	Production Occupations
514	*Metal Workers and Plastic Workers*
5140	*Metal Workers and Plastic Workers*
51401	*Computer Control Programmers and Operators*
514011	*Computer-Controlled Machine Tool Operators, Metal and Plastic*
514012	*Computer Numerically Controlled Machine Tool Programmers, Metal and Plastic*
53	Transportation and Material Moving Occupations
55	Military Specific Occupations

Table 2-5: Standard Classification of Transported Goods

SCTG Code	Commodity Description
00	All Commodities
01	Live animals and live fish
02	Cereal grains
03	Other agricultural products
04	Animal feed and products of animal origin, nec
05	Meat, fish, seafood, and their preparations
06	Milled grain products and preparations, and bakery products
07	Other prepared foodstuffs and fats and oils
08	Alcoholic beverages
09	Tobacco products
10	Monumental or building stone
11	Natural sands
12	Gravel and crushed stone
13	Nonmetallic minerals nec
14	Metallic ores and concentrates
15	Coal
17	Gasoline and aviation turbine fuel
18	Fuel oils
19	Coal and petroleum products, nec
20	Basic chemicals
21	Pharmaceutical products
22	Fertilizers
23	Chemical products and preparations, nec
24	Plastics and rubber
25	Logs and other wood in the rough
26	Wood products
27	Pulp, newsprint, paper, and paperboard
28	Paper or paperboard articles
29	Printed products
30	Textiles, leather, and articles of textiles or leather
31	Nonmetallic mineral products
32	Base metal in primary or semifinished forms and in finished basic shapes
33	Articles of base metal
34	Machinery
35	Electronic and other electrical equipment and components and office equipment
36	Motorized and other vehicles (including parts)
361	*Motorized vehicles for the transport of less than 10 people*
3610	*Motorized vehicles for the transport of less than 10 people*
36101	*Automobiles and mini-vans except parts…*
36109	*Other except parts…*
37	Transportation equipment, nec
38	Precision instruments and apparatus
39	Furniture, mattresses and mattress supports, lamps, lighting fittings, and illuminated signs
40	Miscellaneous manufactured products
41	Waste and scrap
43	Mixed freight
99	Commodity unknown

additional detail. There are a total of 42 two digit codes excluding the one for all commodities. At the four or five digit level SCTG categories contain the products of only one industry and, therefore can be associated with NAICS codes. Unfortunately, these SCTG categories are generally unpublished in the US. SCTG codes can be approximately connected with NAICS codes for the purpose of this report.

2.5.4 Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI)

Manufacturing generates a wide variety of impacts on the environment and makes use of a wide variety of natural resources. TRACI (the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts) was developed as a set of sustainability metrics for a number of purposes, including life cycle assessment. The impact factors used in this report (see Table 2-6) are based on the 12 TRACI impact factors. The original version of TRACI was released in 2002 and has been updated since then. These 12 impact factors are used to examine environmental impacts and use of natural resources.[5]

Table 2-6: Impact Factors

Items to be measured	Units
Global Warming	kg CO2 eq
Acidification	H+ moles eq
HH Criteria Air	kg PM10 eq
Eutrophication	kg N eq
Ozone Depletion Air	kg CFC-11 eq
Smog Air	kg O3 eq
ecotox	CTUe
HH_can	CTUHcan
HH_noncan	CTUHnoncan
Primary Energy Consumption	thousand BTU
Land Use	acre
Water Consumption	kg

[5] For more information on the impact factors go to http://ws680.nist.gov/Bees/Help.aspx

3 Industry Operations Data

Resources are broken down into three basic elements: time, labor, and natural resources, including environmental impacts. The following sections discuss the data available for tracking the use of these resources. There are two approaches to tracking industry activity. The first is often referred to as the top-down approach. The top down approach uses national economic data that tracks activity at the industry, sector, and subsector levels, as defined by a standard categorization. In the bottom-up approach an analyst collects detailed data on inputs akin to collecting data on the factory floor. The top-down approach provides estimates that are far more comprehensive while the bottom-up approach provides more detail. Using the bottom-up approach to create a comprehensive examination is often technically infeasible and cost prohibitive. The following sections outline top-down data and bottom-up data.

3.1 Top Down Data

Data at the broadest level is readily available, allowing for a top down approach to examine industry activity. The following sections describe the data for this approach. Section **Error! Reference source not found.** discusses the data for looking at the inter-ndustry interactions, which includes the purchases from one industry for production in another. Section 3.1.2 discusses environmental and natural resource data for tracking the natural resources consumed in production. Inventory data is used for tracking time and is discussed in Section 3.1.3. Occupational data is used to examine production activities and is discussed in Section 3.1.4. The last topic is building and energy data provided by the Energy Information Administration and is discussed in Section 3.1.5.

3.1.1 Inter-Industry Data

Annual input-output data is available from the Bureau of Economic Analysis (BEA) for the years 1997 through 2013. These tables provide data on the inter-industry relationships for 71 industries. Every five years the BEA computes Benchmark input-output tables, which tends to have over 350 industries. [6] In 2007, there were 389 industries in the Benchmark data. This data is provided in the form of make and use tables. Make tables show the production of commodities (products) by industry, as illustrated in Table 3-1. Use tables show the components required for producing the output of each industry, as illustrated in Table 3-2. The codes are altered NAICS codes that represent different levels of aggregation. There are two types of make and use tables: “standard” and “supplementary.” Standard tables closely follow NAICS and are consistent with other economic accounts and industry statistics, which classify data based on establishment. Note that an “establishment” is a single physical location where business is conducted. This should not be confused with an “enterprise” such as a company, corporation, or institution. Establishments are classified into industries based on the primary activity within the NAICS code definitions. Establishments often have multiple activities. For example, a hotel with a restaurant has income from lodging, a primary activity, and from food sales, a secondary activity. An establishment is classified based on its primary

[6] Bureau of Economic Analysis. November 2014. Input-Output Accounts Data. <http://www.bea.gov/industry/io_annual.htm>

activity. Data for an industry reflects all the products made by the establishments within that industry; therefore, secondary products are included.

Supplementary make-use tables reassign secondary products to the industry in which these products are primary products. The data in this report utilizes the original make-use tables. The make-use tables are used for input-output analysis as developed by Wassily Leontief. Within this model, economies of scale are ignored; thus, it operates under constant returns to scale. The model also assumes that a sector uses inputs in fixed proportions.

Table 3-1: Part of a Make Table from the 2007 Benchmark Input-Output Data

Code	Industry Description	336111 (Automobile manufacturing)	336112 (Light truck and utility vehicle manufacturing)	336120 (Heavy duty truck manufacturing)	…	Total Industry Output
336111	Automobile manufacturing	77 691	4 061	45	…	**87 807**
336112	Light truck and utility vehicle manufacturing	2 222	156 703	333	…	**160 904**
336120	Heavy duty truck manufacturing	0	1	19 412	…	**20 011**
336211	Motor vehicle body manufacturing	0	555	4 282	…	**12 235**
⋮	⋮				…	
T007	**Total Commodity Output**	**80 444**	**161 731**	**24 246**	**…**	**26 151 297**

Table 3-2: Part of a Use Table from the 2007 Benchmark Input-Output Data

Code	Commodity Description	336111 (Automobile manufacturing)	336112 (Light truck and utility vehicle manufacturing)	336120 (Heavy duty truck manufacturing)	…	Total Final Uses	Total Commodity Output
336111	Automobile manufacturing	104	0	0	…	**80 339**	**80 444**
336112	Light truck and utility vehicle	0	0	0	…	**161 716**	**161 731**
336120	Heavy duty truck manufacturing	0	0	50	…	**20 701**	**24 246**
336211	Motor vehicle body manufacturing	1 092	1 263	18	…	**3 292**	**6 834**
⋮	⋮				…		
T005	**Total Intermediate**	**66 129**	**130 438**	**16 342**	**…**		
V00100	Compensation of employees	13 058	6 191	2 386	…		
V00200	Taxes less subsidies	284	129	35	…		
V00300	Gross operating surplus	8 336	24 146	1 248	…		
T006	**Total Value Added**	**21 677**	**30 466**	**3 669**	**…**	**14 477 634**	
T008	**Total Industry Output**	**87 807**	**160 904**	**20 011**	**…**		**26 151 297**

This report uses an industry-by-commodity format as outlined in Horowitz and Planting.[7] This accounts for the fact that an industry may produce more than one commodity or product such as secondary and by-products. This calculation, however, does not take into account the fact that competitive imports are included in the make-use tables; therefore, to analyze the domestic manufacturing industry's inter industry relationships imports must be removed. This is done by subtracting imports proportionally throughout the use matrix.

When examining a sector, such as automotive manufacturing, there are two types of activities: the activities within that industry and the purchases from other industries that go into that industry. The primary measure of output in the input-output accounts is gross output, which is similar to shipments from the Annual Survey of Manufactures. In general, gross output includes the value of both intermediate product and final product measured using market value (revenues received) for goods and services. With much of the data being from the Economic Census, the basic measure used for each industry varies, but is often referred to as "receipts." It is identified as shipments for mining and manufacturing, revenue for utilities, sales for merchant wholesale trade and retail trade, receipts for most services, and commissions for commodity brokerage. For the purpose of this report, it will simply be called output.

3.1.2 Environmental and Natural Resource Data

For environmental data, this report applies a suite of environmentally extended input-output databases for Life Cycle Assessments (LCA) developed under contract to NIST by Dr. Sangwon Suh of the Bren School of Environmental Science and Management at the University of California, Santa Barbara.[8] This data has been utilized in a number of environmental efforts, including NIST's Building for Environmental and Economic Sustainability (BEES) and Building Industry Reporting and Design for Sustainability (BIRDS) tool. This data utilizes TRACI impacts factors; therefore, there are twelve measures of environmental impacts: global warming, primary energy consumption, human health air pollutants, human health – cancer, water consumption, ecological toxicity[9], eutrophication[10], land use, human health – non-cancer, smog formation, acidification, and ozone depletion. The data is organized by 2002 BEA codes for the Benchmark Input-Output tables, as illustrated in Table 3-3.

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[7] Horowitz, Karen J. and Mark A. Planting. September 2006. Concepts and Methods of the Input-Output Accounts. <http://www.bea.gov/papers/pdf/IOmanual_092906.pdf>

[8] This work is based on Suh, S. Developing a sectoral environmental database for input-output analysis: the comprehensive environmental data archive of the US, Eco. Sys. Research., 2005, 17: 4, 449-469.

[9] The potential of a chemical released into the environment to harm terrestrial and aquatic ecosystems.

[10] The addition of mineral nutrients to the soil or water, which in large quantities can result in generally undesirable shifts in the number of species in ecosystems and a reduction in ecological diversity

3.1.3 Inventory and Transportation Data

The Annual Survey of Manufactures (ASM) is conducted every year except for years ending in 2 or 7 when the Economic Census is conducted.[11] The ASM provides statistics on employment, payroll, supplemental labor costs, cost of materials consumed, operating expenses, value of shipments, value added, fuels and energy used, and inventories. It uses

Table 3-3: Layout for the Environmentally Extended Input-Output Table

Code	Description	kg CO2 eq	H+ moles eq	kg PM10 eq	kg N eq	kg CFC-11 eq	kg O3 eq	CTUe	CTUHcan	CTUHnoncan	thousand BTU	acre	kg
336111	Automobile manufacturing												
336112	Light truck and utility vehicle manufacturing												
336120	Heavy duty truck manufacturing												
⋮	⋮												

a sample survey of approximately 50 000 establishments with new samples selected at 5-year intervals. The ASM data allows the examination of multiple factors (value added, payroll, energy use, and more) of manufacturing at a detailed subsector level. The Economic Census, used for years ending in 2 or 7, is a survey of all employer establishments in the U.S. that has been taken as an integrated program at 5-year intervals since 1967. Both the ASM and the Economic Census use NAICS classification, as illustrated in Table 3-4; however, prior to NAICS the Standard Industrial Classification system was used. [12] The Economic Census sent out nearly 4 million forms to businesses representing all US locations and industries.

The inventory data from the Economic Census and Annual Survey of Manufactures is broken into materials inventory, work-in-process inventory, and finished goods inventory. It is important to note that a finished product for an establishment in one industry might be reported as a raw material by an establishment in a different industry. For example, the finished product inventories of a steel mill might be included in the material inventories of a stamping plant. The inventory data does not have a breakout for transport time or down time; therefore, other data must be used for these purposes.

The US Department of Transportation has integrated a variety of data sources, including the Commodity Flow Survey, to create a wide-ranging picture of freight movement in the US. This data is published as the Freight Analysis Framework (FAF), which provides data on the tons, value, and ton-miles of freight movement in the US by commodity, as

[11] US Census Bureau. Annual Survey of Manufactures. <http://www.census.gov/manufacturing/asm/index.html>

[12] Census Bureau. "Annual Survey of Manufactures." < http://www.census.gov/manufacturing/asm/>

illustrated in Table 3-5. This data can be used to better understand the role of transportation in the production of goods and services. The inventory data from the Economic Census and Annual Survey of Manufactures includes items in transport; therefore, for this report transportation time is left for future research. Among the data for transportation, is the domestic flows of vehicles and parts, as illustrated in Figure 3-1. This information is provided for 40 commodity types by mode of transport for each origin/destination combination. The triangles in the figure represent one of the top five

Table 3-4: Annual Survey of Manufactures and Economic Census Inventory Data Layout

NAICS Code	Description	Total inventories, beginning of year	Finished goods inventories, beginning of year	Work-in-process inventories, beginning of year	Materials and supplies inventories, beginning of year	Total inventories, end of the year	Finished goods inventories, end of year	Work-in-process inventories, end of year	Materials and supplies inventories, end of year
336111	Automobile manufacturing								
336112	Light truck and utility vehicle								
336120	Heavy duty truck manufacturing								
336211	Motor vehicle body manufacturing								
⋮	⋮								

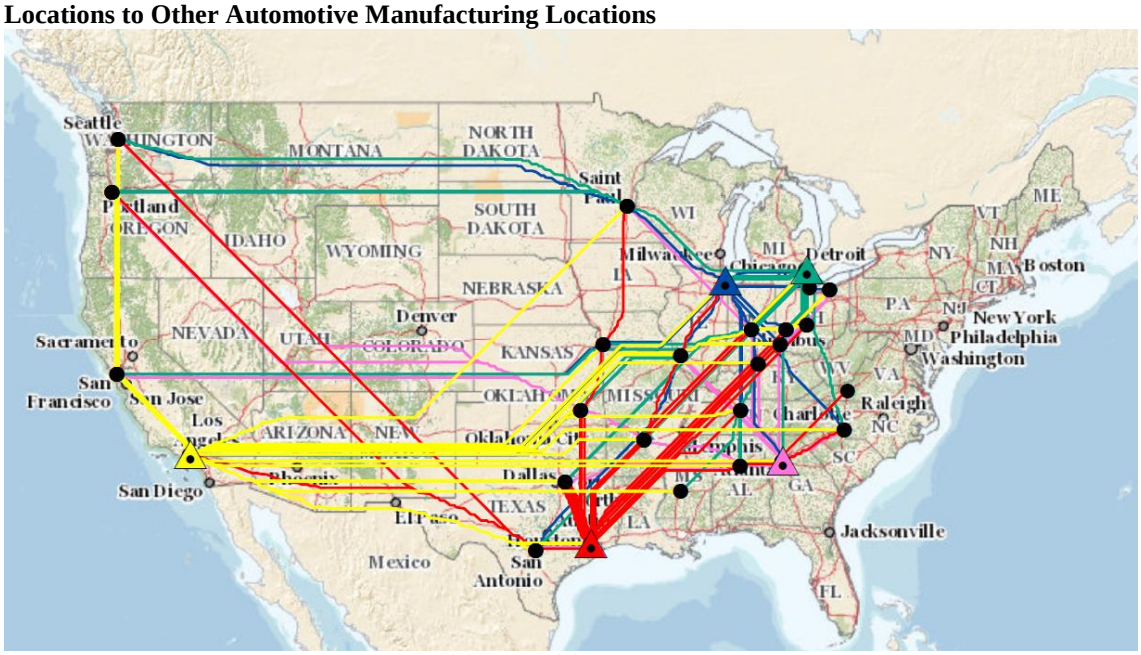
Table 3-5: Data Layout for Freight Information from the Commodity Flow Survey

		Truck				Rail				Water				Air			
SCTG Code	**Commodity Description**	Value	Tons	Ton-miles	Avg Miles per Shipment	Value	Tons	Ton-miles	Avg Miles per Shipment	Value	Tons	Ton-miles	Avg Miles per Shipment	Value	Tons	Ton-miles	Avg Miles per Shipment
00	All Commodities																
01	Live animals and live fish																
02	Cereal grains																
03	Other agricultural products																
⋮	⋮																

production locations. The lines are color coordinated to show movement from those locations.

In order to estimate the work-in-process downtime (i.e., the time that materials are in work-in-process, but the plant is closed) one can employ data from the Survey of Plant Capacity Utilization. This data provides quarterly statistics on the rates of capacity utilization for the US manufacturing industry by NAICS code. It surveys 7500 establishments selected from the Economic Census. They are selected from the Census Bureau's Business Register with updated information from the Economic Census. They

Figure 3-1: Transportation of Motorized Vehicles and Parts by Truck from the Top Five Production Locations to Other Automotive Manufacturing Locations



Source: Freight Analysis Framework. 2007. <http://faf.ornl.gov/fafweb/Extraction2.aspx>
Note: Triangles represent one of the five production locations. The color of the triangle matches the lines that show movement from that location.

are selected with probabilities proportionate to their value of shipments within each industry. In addition to providing capacity utilization, it also provides data on the average plant hours per week in operation for an industry. "Simple weighted estimates of the plant hours are formed by applying the plant's sample weight to its respective values and adding these weighted values across the reporting plants. The average is formed as the ratio of the plant hours weighted sum to the sum of the weights for the reporting plants."[13]

3.1.4 Labor Data

The Bureau of Labor Statistics maintains an Occupational Employment Statistics (OES) program, which produces employment and wage estimates using the Standard Occupational Classification System and the North American Industry Classification

[13] US Census Bureau. "Survey of Plant Capacity Utilization: How the Data are Collected." <http://www.census.gov/manufacturing/capacity/how_the_data_are_collected/index.html>

Table 3-6: Illustration of the Layout for the Occupational Employment Data

		Standard Occupational Classification System				
		514031	514032	514033	514034	…
NAICS	Description	Cutting, Punching, and Press Machine Setters, Operators, and Tenders, Metal and Plastic	Drilling and Boring Machine Tool Setters, Operators, and Tenders, Metal and Plastic	Grinding/Lapping/Polishing/Buffing Machine Tool Setters, Operators, and Tenders, Metal and Plastic	Lathe and Turning Machine Tool Setters, Operators, and Tenders, Metal and Plastic	…
336000	Transportation equipment					
336100	Automobile/light duty vehicles					
336200	Body and trailers					
336300	Vehicle parts					
⋮	⋮					

System.[14] It includes over 800 occupations and over 450 industries; however, archived data covers fewer industries. The data is gathered through surveys and covers full-time and part-time wage and salary workers in nonfarm industries. The self-employed, owners and partners in unincorporated firms, household workers, or unpaid family workers are not covered in the survey. The data is available for the nation as a whole as well as by state, metropolitan area, and nonmetropolitan area. The OES surveys approximately 200 000 establishments every six months on a three-year survey cycle that results in 1.2 million establishments being surveyed. It is provided by NAICS codes and by the Standard Occupational Classification System, as illustrated in Table 3-6.

3.1.5 Building Data and Process Data

The Energy Information Administration collects energy information and building characteristics for commercial, industrial, and residential activities. Manufacturing data is collected in the Manufacturing Energy Consumption Survey that collects information on manufacturing establishments, their energy-related building characteristics, energy consumption, and energy expenditures.[15] It is conducted on a quadrennial basis and samples approximately 15 500 establishments drawn from a nationally representative sample frame that includes 97-98 % of the manufacturing payroll. Data is categorized by the NAICS codes, as illustrated in **Error! Reference source not found.**. Not shown in he table is data by NAICS on the square feet of building space associated with that industry.

[14] Bureau of Labor Statistics. Occupational Employment Statistics. <http://www.bls.gov/oes/>
[15] Energy Information Administration. Manufacturing Energy Consumption Survey. <http://www.eia.gov/consumption/manufacturing/>

In addition to the resources consumed in production, resources are also consumed when the consumer uses a manufactured product. The Energy Information Administration's Residential Energy Consumption Survey provides data on the end use of consumer energy, as does the Commercial Energy Consumption Survey. The residential survey breaks energy use into appliances, televisions, computers & electronics, heating, cooling, and water heating. This information could be used to break out the energy consumed by the final products; however, this is left for future research.

3.2 Bottom up Data

A search for bottom-up data revealed that this type of data is scarce, difficult to acquire, and often proprietary. Much of the proprietary data belongs, of course, to the manufacturers who have economic and strategic reasons for not wishing to disclose the information. Some of the other proprietary data is in the hands of trade groups or membership organizations that manufacturers belong to and which generally do not disclose their data publicly. Some independent organizations like the Center for Automotive Research, CAR, have pre-existing relationships with the major automotive manufacturers that makes data collection relatively easier. But for the average non-connected person or organization this data collection is very difficult. Indeed, the authors were unable to acquire this type of data. This makes it difficult to match generally available bottom-up data with top-down data. It reveals that bottom-up data will need to be collected and developed on an ad hoc basis. In addition to having limited availability, the bottom-up data that is available for manufacturing does not, typically, match up well with the top-down data. Environmental data, however, is somewhat of an exception. It is available from a number of sources but it is not directly connected to top-down categories, making it difficult to bring them together. One prominent example is the German company, Thinkstep (formerly PE International), which offers a range of services and products connected with environmental sustainability through its GaBi LCA (Life-Cycle Assessment) for the automotive industry. However, this data deals with greenhouse emissions and environmental flows resulting from the automotive manufacturing process and deals with economic questions only tangentially.

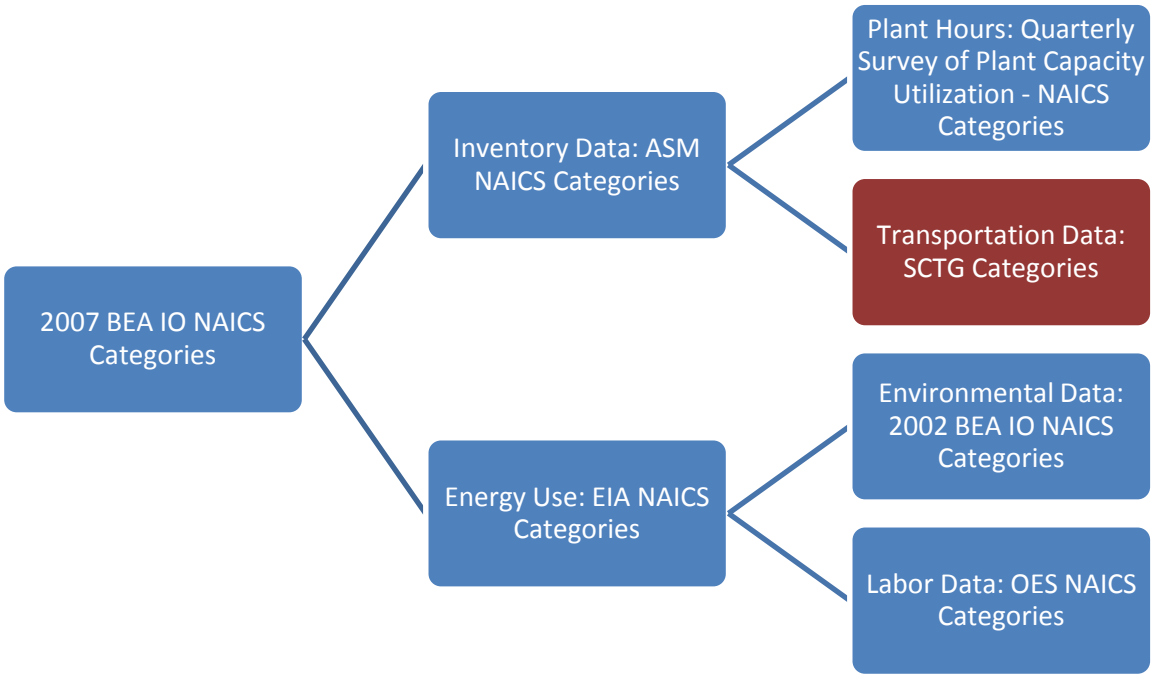
Table 3-7: Illustration of the Layout for Energy use Data from the Energy Information Administration

NAICS Code	Description	**TOTAL FUEL CONSUMPTION**	**Indirect Uses-Boiler Fuel**	Conventional Boiler Use	CHP and/or Cogeneration Process	**Direct Uses-Total Process**	Process Heating	Process Cooling and Refrigeration	Machine Drive	Electro-Chemical Processes	Other Process Use	**Direct Uses-Total Nonprocess**	Facility HVAC	Facility Lighting	Other Facility Support	Onsite Transportation	Conventional Electricity Generation	Other Nonprocess Use	**End Use Not Reported**
336111	Automobile manufacturing																		
336112	Light truck/utility vehicle																		
⋮	⋮																		

4 Top Down Model of Industry Operations Activity

Although the majority of the datasets discussed in Section 3.1 follow the NAICS codes, they have varying degrees of aggregation. As discussed previously, there are differing levels of detail with the two digit NAICS being the least detailed and the six digit NAICS being the most detailed. The datasets that follow the NAICS codes have varying levels of detail both within and between datasets. The BEA Input-Output data has, for example, some data categorized by as few as three digit NAICS and other data categorized as much as six digit NAICS. Similar issues occur in the other datasets. Additionally, the BEA does not strictly follow the NAICS codes for construction. For this report, data has been mapped to the detail level found in the 2007 Benchmark Input-Output data, as illustrated in Figure 4-1. The BEA energy data is broken out by type of use from the Energy Information Administration. The environmental data and labor data are mapped to this augmented BEA NAICS categories. Inventory data is mapped to the BEA NAICS categories, but this data only applies to manufacturing industries. Plant hours are used to augment inventory data and transportation data could be used to augment inventory data; however, it has been left for future research and is shown in red. When the level of NAICS detail does not match the BEA data, it is either aggregated up to the BEA data or it is estimated. The transportation data does not use NAICS, but has similar categories. The following sections describe the calculations and aggregation methods used.

Figure 4-1: Mapping to the BEA IO NAICS Categories



4.1 Input Output Analysis

Tracking the items required for the production of a product requires not only understanding the resources used in the assembly of the final product, but also the extraction of the natural resources, refining of natural resources, assembly of parts, and other supply chain resources. Tracking this information requires data on the inter-industry interactions. The BEA input-output data provides this information in the form of make tables and use tables. These tables can be used to calculate a matrix that shows the inter-industry interactions. This report calculates a domestic industry-by-commodity matrix that shows the domestic industry activity required to produce a selected commodity.[16] In effect, the results show the dollars of national output from each industry required to produce each commodity for the entire US economy.

The BEA input-output data provides estimates of energy use; however, it doesn't provide the detail in how the energy is used, which is an important issue in tracking industry operations. In order to better understand energy use, the Manufacturing Energy Consumption Survey (MECS) was used to breakout the BEA data to show not only how much energy is used, but what it is used for. The energy use categories provided include: indirect uses-boiler fuel, process heating, process cooling and refrigeration, machine drive, electro-chemical processes, other process use, facility HVAC, facility lighting, facility support, onsite transportation, other non-process use, and end use not reported. Electric power generation, transmission, and distribution from the BEA data is broken into these categories by portioning out electric power by proportions calculated from the Energy Information Administration. It is important to note that companies sometimes generate their own electricity. Although the data available allows for this to be broken out, this report leaves that for future analyses.

4.2 Labor

The Bureau of Labor Statistics employment data from the Occupational Employment Statistics can be matched with the BEA IO NAICS categories, as it is categorized by NAICS by occupation. When the BEA data had a NAICS code at a lower level of detail than the occupation data, the occupation data was aggregated up to the BEA level of detail. If the occupation data was at a lower level of detail then the BEA levels were estimated by assuming the proportion of the cost of compensation in the BEA was the same as that for employment. This provides an estimate of occupational employment by industry by the NAICS level of detail. To estimate the hours of labor, these estimates are multiplied by the average hours per week for each occupation and, then, multiplied by the total weeks per year.

When examining a specific product commodity such as automotive manufacturing, the input-output calculations were used to estimate the output from each industry required to produce the given product. The proportion of the total output needed from each industry was multiplied by the occupational employment for each industry to estimate the amount

[16] This report uses an industry-by-commodity domestic total requirements table produced using methods outlined in Bureau of Economic Analysis. Concepts and Methods of the US Input-Output Accounts. September 2006. <http://www.bea.gov/papers/pdf/IOmanual_092906.pdf>

of labor. The result is a matrix of the amount of labor needed, categorized by NAICS by occupation, to produce the relevant commodity.

4.3 Time

Metrics in operations management often measure the time that it takes to produce a product. Having too many materials and goods on hand is often considered an indication of a problem, as inventory deteriorates over time, consumes resources to maintain it, and ties up capital. It is important to note that time and labor hours are not equivalent. Multiple people working simultaneously for an hour results in multiple labor hours per hour; however, the time that passes is only one hour. Additionally, processes that are completely automated do not require labor; therefore, an hour of a production process may pass with minimal or no labor. Two measures are necessary to track the industry time it takes to produce a product: inventory turns and an industry reiteration rate.

4.3.1 Inventory Turns

Inventory turnover is the number of times inventory is sold or used in a time period such as a year. It is calculated as the cost of goods sold divided by the average inventory. The Annual Survey of Manufacturing has data to calculate the cost of goods sold. It is the sum of payroll; benefits; materials; depreciation; capital expenditures; rental payments; other expenses; and beginning of year inventories less end of year inventories. Inventories are calculated as the average of the beginning of year inventories and end of year inventories. The Annual Survey of Manufactures provides data on total inventories, material and supplies inventories, work-in-process inventories, and finished goods inventories by NAICS code. The days that a dollar spends in each of these inventories can be calculated by taking the total number of days in a year and dividing it by the number of inventory turns. One item that this calculation excludes is the down time for work-in-process; that is, the time that a good is in work-in-process but the factory is actually closed. To make this calculation we use data from the Quarterly Survey of Plant Capacity Utilization, which provides the average plant hours by NAICS code. This data can be used to estimate the proportion of work-in-process time that is actually down time.

4.3.2 Industry Reiteration Rate

Using the Annual Survey of Manufactures data to make the inventory calculations provides the average days a dollar spends in inventory for an establishment in a particular NAICS code; however, a material that is moving through an industry may be processed in more than one establishment in an industry, as illustrated in Figure 4-2. For example, a chemical plant could produce chemical A while another plant produces chemical B. A third plant might be combining chemical A and B to produce another chemical. Both chemical A and B were processed at two plants that were both within the chemical manufacturing industry. That would mean that these items were in inventory approximately twice as long as would be calculated using the inventory data from the Annual Survey of Manufactures. This paper proposes a method to estimate the number of times a material is processed in one industry, which will be referred to as the industry reiteration rate. Two datasets are used to make this estimation: the BEA Benchmark Input-Output Use data from 2007 and the Annual Survey of Manufactures. The Benchmark Use table provides inter-industry purchases, including the purchases an

industry makes from itself. The Annual Survey of Manufactures provides the cost of materials, parts, containers, and packaging used as well as the cost of resales, which is items purchased and resold without being altered. The inter-industry purchases is divided by the sum of the cost of materials, parts, containers, and packaging used and the cost of resales. This provides a proportion of material purchases from the same industry:

$$P = \frac{Puchases\ an\ Industry\ Makes\ from\ Itself}{Materials, Parts, Containers, and\ Packaging + Resales}$$

Where P = Proportion of materials, parts, containers, packaging, and resales that are purchased from an entity in the same industry.

This is an average proportion of materials purchased from an entity within the same industry; thus, if P equals 0.3 for industry X, then, on average, an establishment in industry X purchases 30 % of its materials from another establishment in that industry. If it is assumed that each establishment in an industry maintains this proportion of purchases, then we can estimate how many establishments a material goes through before it is diminished below a certain level. In the example of P equaling 0.3 or 30 %, after two establishments 9 % of the material has gone through two establishments (30 % multiplied by 30 %). After three establishments, 2.7 % of the material has been through three establishments (30 % multiplied by 30 % multiplied by 30 % or 0.03 to the power of 3). With the assumption that each establishment in an industry maintains this proportion of purchases, then, one can calculate the number of establishments a dollar goes through before it is diminished below a certain threshold. Without a threshold, the material would be calculated as going through the industry indefinitely. In our example, no matter what power we raise 0.03 to, it will never reach 0. One can calculate the number of establishments a dollar goes through before it is diminished below a certain threshold using a logarithmic function with base P, which is the industry reiteration rate:

$$Industry\ Reiteration\ Rate = log_p T$$

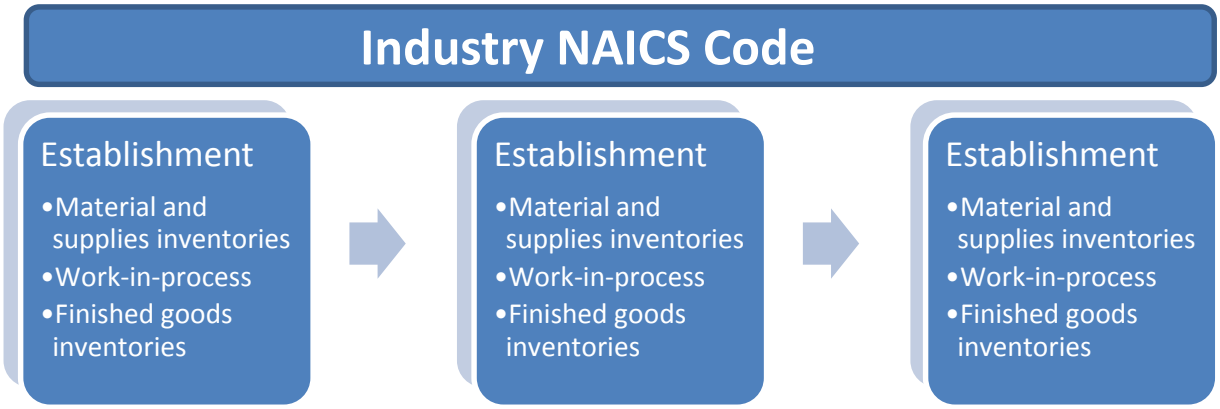
Where
T = The selected threshold, which is between 0 and 1
P = Proportion of materials, parts, containers, packaging, and resales that are purchased from an entity in the same industry.

For example, let's say that industry x has a proportion P of 0.50 and one selects a threshold of 0.125. The industry reiteration rate would be:

$$log_{0.5} 0.125 = 3$$

This suggests that, given this threshold, a material is likely to go through around three establishments in industry x, on average. For those industries that are below the threshold, the reiteration rate is simply 1. The threshold represents the level at which it is believed materials would only go through one establishment in that industry; therefore, for values of P that are less than T the industry reiteration rate is 1. A threshold can be

Figure 4-2: Illustration of Tracking a Material through an Industry



selected by examining *P* values from industries where a product only goes through one establishment in that industry. The threshold would then either be equal to one of those *P* values or based on them (e.g., average or maximum value). For this report a threshold of 0.03 was selected. Industries that would be expected to go through only 1 establishment tended to have a *P* value of 0.03 or less. For example, printing is likely to go through only one establishment and had a *P* value of 0.028. Another example with a value of 0.002 is automobile manufacturing (i.e., assembly), which is an industry that is separate from auto parts production and, therefore, would likely only go through one establishment. As the threshold is lowered the reiteration rate increases; therefore, a higher threshold moves toward assuming that a material moves through fewer establishments while a lower threshold moves toward assuming it moves through more establishments.

The reiteration rate provides a rate that can be compared between industries and represents the number of establishments a material would go through in a particular industry. It must be noted, that this is not a perfect measure. In order to know the average number of establishments a material travels through, it would be necessary to map the interactions of the hundreds, thousands, and even tens of thousands of establishments in each industry. Such an effort would be technically infeasible; therefore, we must rely on imperfect metrics.

4.4 Natural Resources and Environmental Impacts

The current data available to track environmental impacts is categorized by NAICS codes at the detail level specified in the 2002 BEA Benchmark Input-Output data. The process of Contribution Analysis is used to identify and quantify the sustainability impacts of manufacturing activities. This process evaluates the contribution that each industry makes to life-cycle environmental impacts, which are derived from 6 204 environmental inputs and outputs throughout the production supply chain. The environmental data represents the per dollar environmental impact; however, it is in terms of 2002 dollars. Therefore,

the environmental data is adjusted to the 2007 BEA data using the Consumer Price Index from the Bureau of Labor Statistics. These values are then multiplied by the per industry dollars of output needed for automotive manufacturing for each industry.

4.5 Aggregated Input-Output Model

The final analysis uses input-output analysis combined with the previously discussed industry data to estimate industry operations activity. Using input-output analysis, the proportion of each industry that is purchased by the industry being studied (the automotive manufacturing industry in this example), is used to estimate the labor and other resources that are dedicated to that industry production. The aggregated dataset layout is shown in Table 4-1. This is a 1238 by 397 matrix resulting in over 490 000 information points on the US economy with over 290 000 being related to manufacturing.

Table 4-1: Illustration of Final Data Layout (columns are NAICS codes)

Data type	Description/Units	BEA 2007 Benchmark IO NAICS CODES				Energy Data										
		336111 Automobiles	336112 Light trucks	336120 Heavy duty trucks	…	Indirect Uses-Boiler Fuel	Process Heating	Process Cooling/Refridg.	Machine Drive	Electro-Chem. Processes	Other Process Use	Facility HVAC (g)	Facility Lighting	Other Facility Support	Onsite Transportation	Other Nonprocess Use	End Use Not Reported
Environmental Data	Global Warming															
	Acidification															
	HH Criteria Air															
	Eutrophication															
	Ozone Depletion Air															
	Smog Air															
	ecotox															
	HH_can															
	HH_noncan															
	Primary Energy Consumption															
	Land Use															
	Water Consumption															
Transport and Inventory Data	Days in transport															
	Days in material inventory															
	Days in work-in-process															
	Days in final goods inventory															
	Industry reiteration rate															
Energy Data	Indirect Uses-Boiler Fuel															
	Process Heating															
	Process Cooling and Refrigeration															
	Machine Drive															
	Electro-Chemical Processes															
	Other Process Use															
	Facility HVAC (g)															
	Facility Lighting															
	Other Facility Support															
	Onsite Transportation															
	Other Nonprocess Use															
	End Use Not Reported															
Occupation	514031 Cutting and Punching…															
	514032 Drilling and Boring…															
	514033 Grinding/Lapping …															
	514034 Lathe and Turning…															
	⋮															
BEA 2007 Benchmark IO NAICS CODES	336111 Automobiles															
	336112 Light trucks															
	336120 Heavy duty trucks															
	⋮															

5 Case Study in Automotive Manufacturing

This report identifies data and develops a model for tracking industry operations activity. This section applies that model to the automotive manufacturing industry. The first section provides an overview of the industry. This overview provides a qualitative summary of automotive manufacturing. These details provide context for the top down model and also provide context that would be necessary for identifying areas of high resource consumption.

5.1 Overview of Automotive Manufacturing

The automotive industry dates back to the late nineteenth century. More than a century has elapsed since the days when Henry Ford somewhat facetiously said in 1909 that his customers could have any color car "so long as it is black." What characterizes the automotive industry today is variety and a constant state of churn. The changing nature of global consumer preferences is responsible for the sheer breadth of vehicles available, as a Boston Consulting Group publication reports that 30% of all global sales come from the BRIC nations – Brazil, Russia, India, and China.[17]The automotive industry has been characterized by a level of competition in recent years that harkens back to the early days of the industry in the late nineteenth and early twentieth century. A domestic market once dominated by the Big Three – General Motors, Ford, and Chrysler -- yielded to a world where fourteen auto manufacturers have a physical presence in the United States.

The production process for automobiles relies on a number of complex inputs. While each step of the production process is discrete and unique, the steps in the production process also have similar characteristics and work more as an interlocking system with changeable parts than as a series of fully autonomous systems. By isolating each stage of the automotive production process and considering it in the context of the larger whole, certain patterns begin to emerge. Direct examination of these interlocking parts yields a number of interesting insights which can be drawn out in the context of field studies and which also impact the economics of the manufacturing model.

This report focuses on internal combustion engine vehicles; however, it is important to note that electric automobiles have captured the interest of the public and media in a substantial manner. Many do not realize that electric cars were actually the dominant norm in the late nineteenth century and early twentieth century until the successful development of a cost-saving internal combustion engine made electric vehicles of the time seem slow and obsolete. Nevertheless, they are back in the news in a major way. However, this should not obscure the fact that in 2014, electric cars were less than half of one percent of new global vehicle sales.[18]

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[17] Lang, Nikolaus, Stefan Mauerer, Marcos Aguiar, Ewald Kreid, Arindam Bhattacharya, and Christoph Nettesheim. January 2010. Winning the BRIC Auto Markets: Achieving Deep Localization in Brazil, Russia, India, and China. <https://www.bcgperspectives.com/content/articles/automotive_globalization_winning_the_bric_auto_markets/>

[18] Young, Angelo. "Global Electric Car Market: About 43% of All Electric Passenger Cars Were Bought in 2014, Say German Clean Energy Researchers." July 15, 2015. *International Business Times.*

Electric vehicles have some fundamental differences with the standard combustion engine production models. Electric vehicle manufacturers like Tesla face a different calculus in terms of cost and labor than the standard vehicle manufacturers do. They also face challenges in building up an infrastructure of charging stations that their traditional competitors do not face. For that reason, the focus of this section will be on the standard internal combustion-powered motor vehicles and not electric vehicles. However, it should be noted that most of the advancements in automation have been adopted and sometimes modified for the production of electric vehicles.

The following sections discuss the use of computer simulations in auto manufacturing (Section 5.1.1), the processes used in auto manufacturing (Section 5.1.2), and trends in auto manufacturing (Section 0).

5.1.1 Computer Simulation in the Manufacturing Industry

The use of computer-based simulation in the auto manufacturing industry goes back to the 1970s.[19] Since then, the automotive industry has advanced to a stage where it can have "multiple computers running multiple manufacturing simulations in an integrated fashion, combining layout optimization with layout simulation, off-line programming of welding robots."[20] The running of these simulations necessitated the creation of databases (where they did not already exist) to provide the necessary information, which was a positive spillover effect that had a long-term beneficial impact on the availability of reliable information about the auto manufacturing process.

Onur Ulgen and Ali Gunal identified the key categories in the manufacturing industry where simulation is used. There are four basic categories – equipment and layout, variation management, product mix sequencing, and detailed operational issues. It is useful to look at each of the categories to understand just how comprehensive the use of simulation is in the automotive industry, a trend replicated in other manufacturing industries.

"Equipment and layout" refers to simulation designed to sequence issues dealing with manufacturing machines, conveyor length issues, and identification of buffer storage issues. "Variation management" deals with scrap analysis and paint scheduling. "Product mix sequencing" concerns shift scheduling and work on the trim and body lines. "Detailed operational issues" refers to traffic priority management and assembly sequencing.

A more comprehensive treatment of these categories can be found in the chapter by Ulgen and Gunal. But what this overview of the simulation process shows is that the manufacturers are not relying on only one process of simulation to cover the range of

[19] Society for Computer Simulation. GENTLE: Generalized Transfer Line Emulation. Proceedings of the Conference on Simulation in Inventory and Production Control. San Diego, CA: 25-30.
[20] Ulgen, O. and Gunal, A. (1998) Simulation in the Automobile Industry, in Handbook of Simulation: Principles, Methodology, Advances, Applications, and Practice. ed J. Banks. (John Wiley & Sons, Inc., Hoboken, NJ, USA: 1998): 547

activities that takes place in a manufacturing plant. There is no "one size fits all" mentality in the auto manufacturing industry

Rather, over a period of years, the manufacturers have done what all producers usually end up doing, as Adam Smith noted in *The Wealth of Nations* – specializing. They have developed the ability to create simulation processes for each activity in a manufacturing process. These tailored simulation processes emerged through a combination of research, trial-and-error, and a value in process improvement.

For example, a simulation design for product mix sequencing deals with issues of full operation and launch, but not conceptual design. Equipment and layout deals with conceptual design and launch issues but not full operation issues. The specialization of each simulation program necessitates specialization of the skill sets and thus places a premium on workers with specialized knowledge. Thus it is important to realize that automation in the auto manufacturing industry has taken place not only on the processes of the assembly line, but also on the computer programs that guide those manufacturing processes.

5.1.2 Auto Manufacturing Process

As noted earlier, competition from foreign companies as well as the changing tastes of American consumers has dramatically increased the range of automobiles available today. Yet at the same time, automobile manufacturing has retained certain key features over the years. Before discussing the changes that have occurred in automotive manufacturing, it is beneficial to step back and take a bird's eye view of the entire manufacturing process. Looking at the auto manufacturing process in detail reveals a number of lessons that can be applied to the manufacturing industry at large – namely, the waxing and waning of certain raw materials and the parallel processing of different components in separate manufacturing processes.

The auto manufacturing process is usually depicted as having either four or five steps, depending on where in the manufacturing chain one wishes to start. Here, the manufacturing process will be depicted as having five steps, using a comprehensive framework laid out by experts Graeme P. Maxton and John Wormald.[21] The following discussion is indebted to their conceptual framework.

First, the raw materials that go into the making of the car, like steel and aluminum, come in from suppliers. Most of the major auto manufacturers have longstanding relations with certain key suppliers and usually procure their materials from a specialized dealer who often deals only exclusively with that manufacturer. As the economy has been globalized, manufacturers have shown a willingness to break out of their longstanding supply arrangements in pursuit of the lowest cost.

[21] Maxton, Graeme P, John Wormald. Time for a Model Change: Re-engineering the Global Automotive Industry. (Cambridge University Press, New York, NY: 2004): 143.
OICA. 2014 Production Statistics. <http://www.oica.net/category/production-statistics/>

The press shop is the first basic step of the internal manufacturing process. Here the steel and aluminum are converted into panels. The automation that has taken place over the past few decades in the car industry becomes apparent even in this initial stage of the manufacturing process where some of the work that was once performed by human laborers is now carried out by machines. Depending on how well the automated components of the press shop can communicate with each other, the time required for the stamping of panels can vary.

The panels are then transferred to the body shop where they are put together so that the "bodyshell" of the car becomes visible. Generally, all of the non-moveable parts of the car are fixed at this point in time. Parts like the hood and car doors will be installed at a later stage of the process. The trim (seats and glass and the car's electronics) are also installed at a later step. All the welding of the main components has been carried out by the end of this step. The work product is dipped in an anti-rust formula. The bodyshell that comes out of this process is often referred to as the "body in white." This is a somewhat antiquated term that is still widely used in the car industry. It refers to the days when the shell was given a white coat of primer as it exited this step of the manufacturing process.

The body in white proceeds to the paint shop where it is cleaned up, given a coat of primer and then painted in the desired color. It then goes to what is usually the final location, the assembly plant, where a number of processes happen in a precise sequential order. The trim process takes place first in the assembly plant and is more cosmetic in nature, although important functional parts of the automobile are also installed here like the dashboard and seats. After the trim line, the car proceeds to the final assembly.

But a discerning observer would notice that there has been no discussion yet of some of the crucial components of the car – namely, the engine and the transmission. The engine and transmission are among two of the most important parts of what is usually referred to as the "powertrain," which links the engine of an automobile to its axel and thus makes movement possible. The manufacturing of the engine and transmission are important, not only because the automobile cannot function without them but also because they highlight what may be the crucial characteristic of the auto manufacturing process.

That characteristic is the existence of parallel processes. Like other kinds of manufacturers, automotive companies are subject to constraints of time and money. The component parts of a car are diverse in the extreme and it does not make much sense, for example, for the car seat maker to also be the entity that also builds the engine. What was true in Adam Smith's day is true today and specialization is the norm in the auto industry, not the outlier.

Outside of the body in white, none of the most common parts of the car have been created in the account above. What actually happens is that while the body in white is being constructed, primed, and painted, there is a parallel track where everything from the fuel pump to the rear view mirrors is being put together. The major manufacturers have sophisticated supply chains that economists like Dr. Sue Helper and Dr. Mari Sako have

argued are based on principles articulated by the late Dr. Alfred Chandler.[22] Helper and Sako have written about how vertically integrated supply chains need to be managed to prevent "information overload."[23] In theory, the sequencing of the manufacturing process should guarantee that half-built automobiles do not languish while they wait on the assembly line for their component parts. If planned correctly, the component parts will arrive from the parallel track at the moment they are needed. This, and the development of welding robots, also explains a nearly omnipresent fact about the modern auto manufacturing plant – different *types* of vehicles can be sent down the very same assembly line, which is a truly remarkable innovation.

The foundry and the forge are where the engine and transmission emerge from. In the foundry, the engine block is made and then conveyed to a specialized engine plant where it is machined and tested before being sent to the assembly plant. In the forge, the transmission is created to be durable and then sent to a transmission plant where it is also machined and tested before being sent to the assembly plant. In the traditional sequence in which these events play out, the engine needs to be ready before the transmission. Typically, the engine is installed during the trim phase in the assembly plant and the transmission is installed afterwards during the final assembly phase. After the body in white has been supplemented with all of the necessary parts, it is given one final test for defects or performance related issues before being sent out to the distribution network.

5.1.3 The Advent of Smart Manufacturing Technologies in the Automotive Industry

One of the major drivers for these efficiency gains has been the development of what are known as "smart manufacturing" techniques. Smart manufacturing can refer to a variety of practices. In this context, it will refer to the adoption of simulation modeling techniques when modifying the existing manufacturing process at an automotive plant. In a comprehensive piece on the topic, Onur Ulgen and Ali Gunal note that every major auto manufacturer relies on simulation before changing the manufacturing process.[24] Simulations are run for changes above a certain threshold cost. Changes in the auto manufacturing process are meticulously laid out in computer programs where they are analyzed for every change they make over the existing process.

The single biggest change to the manufacturing process over the past few decades has been the advent of robotics and automation, with much of the fundamental change beginning in the 1980s. While the sequencing of automotive manufacturing has remained essentially the same, with cars moving from the body shop to the assembly floor, simulation plays a bigger role than ever before in the automotive manufacturing process with all major manufacturers requiring it before undertaking capital expenditures

[22] Helper, Susan and Mari Sako. 2010 "Management Innovation in Supply Chain: Appreciating Chandler in the Twenty-First Century." Industrial and Corporate Change. Vol 19(issue 2): 399-429.
[23] Ibid
[24] Ulgen, O. and Gunal, A. (1998) Simulation in the Automobile Industry, in Handbook of Simulation: Principles, Methodology, Advances, Applications, and Practice. ed J. Banks. (John Wiley & Sons, Inc., Hoboken, NJ, USA: 1998): 547

or changes to the assembly line process.[25] The automation of the motor vehicle industry is what people refer to, in part, when they discuss "lean manufacturing."

Automation is the single most important transformation that has happened to the steel industry in recent years. As the twentieth century drew to a close, more and more tasks were automated by the development and growth in sophistication of cobots, or collaborative robots, have drastically changed the level and participation of human inputs in the manufacturing process.

The automation of much of the manufacturing process and cobots have also had long-standing impacts on auto manufacturing. Cobots have become prominent in the last decade and a half. Despite all of this change, however, certain key elements of the manufacturing process have remained unchanged. Automobiles are still produced in the same basic order that they have been produced for decades. What has changed is the *time required* for manufacturing various automotive parts and components has been dramatically reduced through efficiency gains.

This has inevitably meant job losses at some stages of the auto manufacturing process, like welding and painting.[26] Professor Erik Brynjolfsson of MIT has argued that we are at a moment in time when job losses due to automation are outpacing the creation of new occupations and that gains in productivity do not necessarily translate into better employment prospects.[27] This view, widely held, has led to complaints and attempts to reverse the trend towards automation in the manufacturing process. But like King Canute and the waves, the forces leading to greater automation are very difficult to resist.

Nevertheless, automotive industry experts like Graeme P. Maxton and John Wormald have pointed out that it is impossible to completely do away with human beings in the automotive manufacturing process.[28] The manufacturing method is extremely complicated, with inputs coming in at all stages of production. Even with advances in artificial intelligence, the fabrication of a car requires human beings at certain stages of the process to ensure the smooth functioning of the assembly line.

Maxton and Wormald argue that automation and lean manufacturing have actually increased the quality of work that human assembly workers are called upon to perform.[29] Before the full advent of automation, they point to the example of a well-known foreign car manufacturer who advertised the fact that they hired more quality control personnel

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[25] Ibid
[26] Rotman, David. June 12, 2013. "How Technology is Destroying Jobs." <http://www.technologyreview.com/featuredstory/515926/how-technology-is-destroying-jobs/>
[27] Charting technology's new directions: A conversation with MIT's Erik Brynjolfsson at McKinsey&Company Insights & Publications at <http://www.mckinsey.com/insights/high_tech_telecoms_internet/charting_technologys_new_directions_a_conversation_with_mits_erik_brynjolfsson>
[28] Maxton, Graeme P, John Wormald. Time for a Model Change: Re-engineering the Global Automotive Industry. (Cambridge University Press, New York, NY: 2004): 143.
OICA. 2014 Production Statistics. <http://www.oica.net/category/production-statistics/>
[29] Ibid

than floor workers. Although the manufacturer was trying to make a statement about how much care it took to ensure that its cars were defect-free, what it was actually implying was that numerous mistakes and errors had already resulted on the assembly line and that quality care professionals were required to correct the problems that had not already been fixed in the manufacturing process.

That is a situation that would not occur in the modern automated car assembly process, at least in theory. "Lean manufacturing" emphasizes the principle that every known defect should be corrected at the stage it occurs at and not be caught at a later stage of the production process.[30] Although some of this error checking can be done by an automated process, there is an active need for engaged human participation at every stage. These human workers need to be trained to spot a range of errors, which requires a great deal of knowledge about the totality of the manufacturing process.[31] In this respect, automation makes *greater* demands on the knowledge base of human workers than the older manufacturing processes did a few decades ago. It also ensures that workers are given jobs that require greater mental dexterity.

It is thus fair to refer to the auto manufacturing process as a knowledge-intensive industry where improvements in critical thinking about the sequential stages of the process can easily translate into efficiency gains, as demonstrated by Helper and Mako. During past economic downturns, there has been a temptation in the auto industry to cut back on research into the manufacturing process to save money. This is particularly misguided in the modern context, which delivers better results and more meaningful work to employees through the deployment of smart management techniques. A number of mathematical practices and quantitative techniques have gone into building the automation revolution that swept the automobile industry some thirty-five years ago.

One of them was Analytic Hierarchical Process, or AHP, an organized methodology for sorting through criteria and sub-criteria to rank order preferences. For example, AHP could be used to look at the various characteristics of a car and then rank order them based on the preferences of the manufacturer. For example, a manufacturer might prefer reliability to durability or maneuverability, based on a preference order of its criteria and sub-criteria using geometric means. AHP has been deployed to study technological diversification in the auto industry.[32] Its insights have also been brought to bear on automotive spare parts, an important topic often neglected in studies of auto manufacturing.[33]

Another technique that has had a larger impact on the automotive manufacturing process is the use of Taguchi Methods. Taguchi Methods are statistical methods developed by the Japanese engineer Dr. Genichi Taguchi with the specific aim of improving the quality

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[30] Ibid
[31] Ibid
[32] Wu, Hsin-Hung and Ya-Ning Tsai. January 2012. "Using AHP to evaluate the criteria of auto spare parts industry." Quality &Quantity. Vol 46(issue 1): 359-364.
[33] Ibid

of manufactured products. According to an article by Lawrence P. Sullivan, Taguchi Methods first came to the U.S. automotive industry in March 1982.[34]

Sullivan emphasizes the point that Taguchi Methods and its related concept, Quality Function Deployment (QFD), are part of a larger mindset called Total Quality Control or TQC.[35] Through the use of loss functions and a belief that externalities should not be ignored by manufacturers, Taguchi methods focus on the manufacturing process and tries to reduce the variation in quality. The Taguchi Loss Function shows that the loss in value of a manufactured good comes not from a singular mistake that deviates from a planned prototype but from an increase in the *variation of the product*, with emphasis being on the customer's perspective.

Although Sullivan notes that Taguchi Methods were originally controversial to U.S. statisticians, Ford adopted the methodology early on and had success with it, which led the other auto manufacturers to also adopt it.[36]

5.1.4 The Role of Raw Materials and Changing Technologies

When discussing the manufacturing process, it does not make sense to just focus on the mechanics of the assembly line. Manufactured goods are combinations of their constituent parts and that is even truer for automobiles. The raw materials that go into the assembly line press shop are thus of vital importance to the manufacturing process. A spike in the price of one of those raw materials or a disruption in its supply chain has massive implications for the automotive manufacturing process.

By weight, the most commonly used component in the modern automobile is steel. Between 60 and 65 percent of an automobile's weight can be attributed to steel.[37] Although aluminum has become increasingly popular in recent years, steel is still favored for two primary reasons – its relatively cheap cost and its malleability, which allows it to be shaped in a variety of fashions with relative ease. Thus the automobile industry which is (correctly) portrayed as being responsive to oil prices, is also impacted by fluctuations in the price of steel. However while steel is being used in the automotive industry as it always was, the steel is of a fundamentally different caliber than it once was. Nowadays, the steel is much stronger, as manufacturers try to move away from their heavy reliance on low-carbon steel, which has between .05 and .25% carbon content.[38]

Safety requirements and changing technology also mean that the body in white is now made up of different kinds of steel, based on their malleability. Computer simulations of crashes help to determine the quality and type of steel being used. The steel used in an automobile can be broken down into two general categories – high/medium strength steel

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[34] Sullivan, L.P. 1987 "The Power of Taguchi Methods to Impact Change in US Companies." 22. <http://www.ame.org/sites/default/files/documents/87Q2A4.pdf>
[35] Ibid 19
[36] Ibid 18
[37] Thomas G.P. "The Future of Steel in the Automotive Industry - An interview with Cees ten Broek." <http://www.azom.com/article.aspx?ArticleID=10538>
[38] Blain, Patrick. Steel Perspectives for the Automotive Industry. Presentation on May 31st, 2012. <http://www.oecd.org/industry/ind/50498824.pdf>

and low-carbon steel. A great deal more low-carbon steel is used because high-carbon steel is difficult to shape and mold. High-carbon steel is also costly because its very nature necessitates that the steel is usually produced in slab form due to it being alloyed and made stronger.

Outside of steel, no auto manufacturing component has shown more growth over the past thirty years than aluminum. Aluminum is lighter than steel and more malleable. European automobiles have made greater progress towards replacing steel with aluminum than their American counterparts have. The move towards greater aluminum use and the requirements for greater fuel economy standards is why OICA (Organisation Internationale des Constructeurs d'Automobiles, a Paris-based automobile manufacturers group) predicts that average vehicle mass peaked in 2009 and has been on a steady downward trend ever since.[39] Nevertheless, the demand for steel in the automotive process is still projected to be higher by 20% over 2000. There is also talk of developing polymers, but more research needs to be done on this topic.

5.1.5 Economic Trends for Automobile Manufacturers

For most of the twentieth century, the United States was the leading producer of automobiles in absolute numbers in the world until 1980 when Japan took the number one spot. Since, then the number one spot has seesawed between the United States, China, and Japan, with China currently in the lead and producing nearly two times the number of vehicles manufactured in the U.S. In 2014 alone, 89.75 million cars and commercial vehicles were produced globally according to statistics kept by OICA, a Paris-based auto manufacturing group.[40] Out of that 2014 total, 11.66 million automobiles, around 13% of the cars, were produced in the United States.[41]

For all of the talk about the decline of manufacturing in the United States over the past few decades, the automotive industry continues to play a vital role in not only the U.S. manufacturing sector, but in the wider national economy. Although vehicle production among some auto manufacturers has decreased, it has increased among others, as seen in Figure 5-1. CAR, the independent nonprofit Center for Automotive Research based out of Ann Arbor, Michigan, issued a comprehensive report in January 2015 estimating that 322,000 people are directly employed by automakers and 805,000 people are employed in an intermediate capacity in the United States for a total of 1,127,000 people.[42] If one is to include all motor vehicle-related manufacturing and auto dealerships, the number of people directly employed swells to 1,553,000 and the number of intermediate employees is 2,316,000 for a total of 3,869,000 people employed by the auto industry.[43]

These numbers from CAR show the impact of the auto manufacturing industry on economies, both local and national. Although a relatively small number of people are

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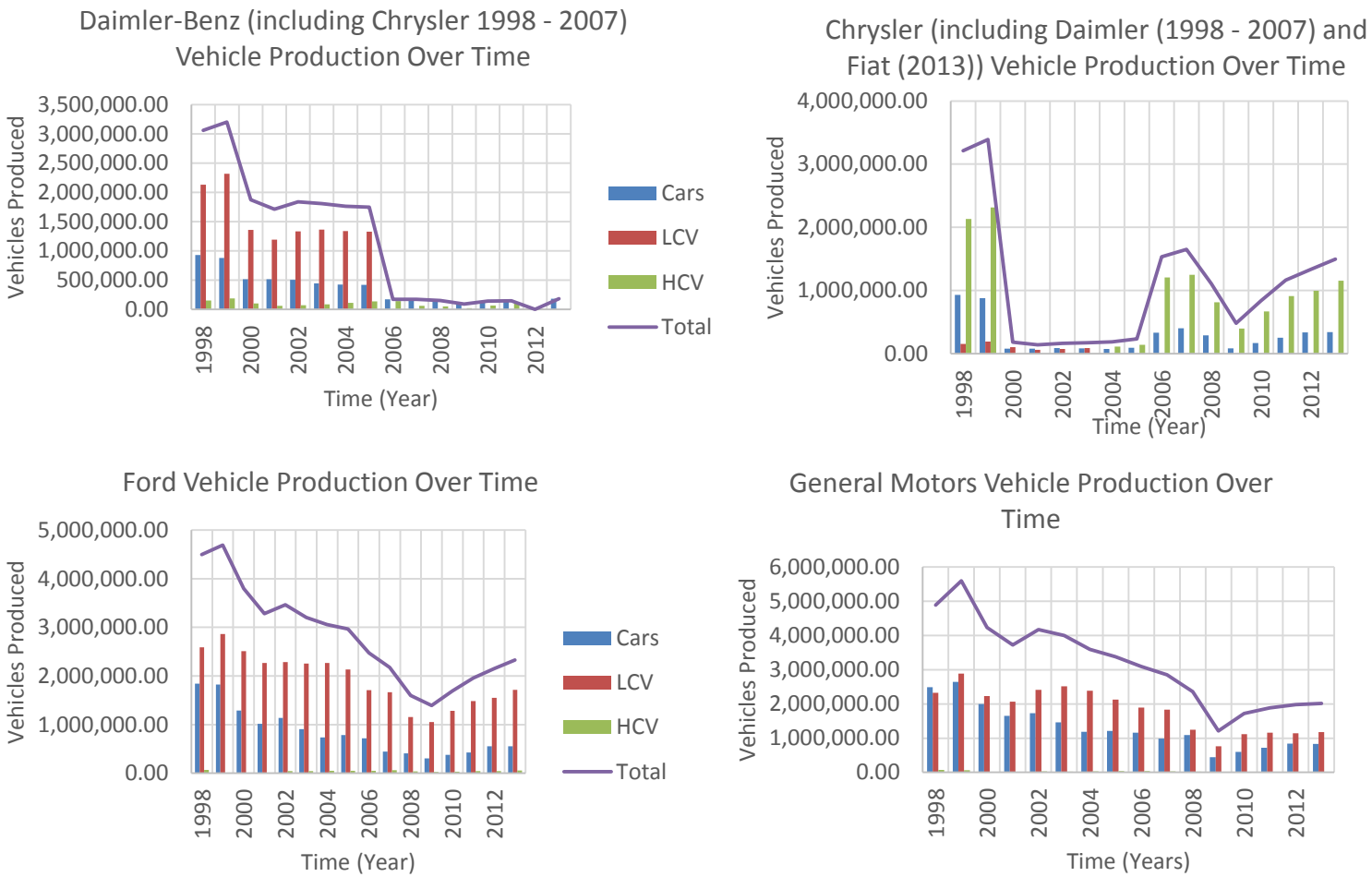
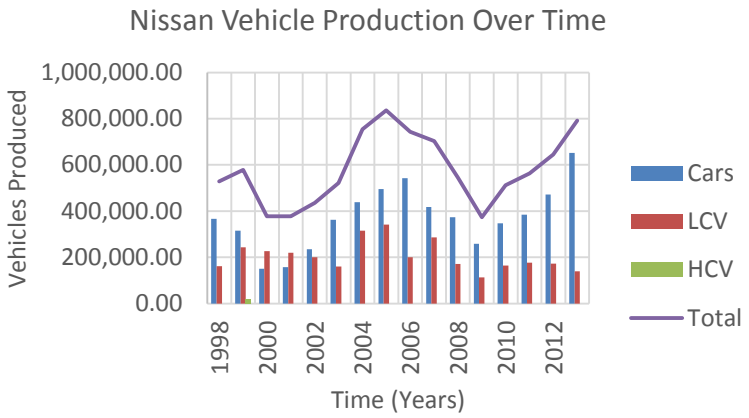
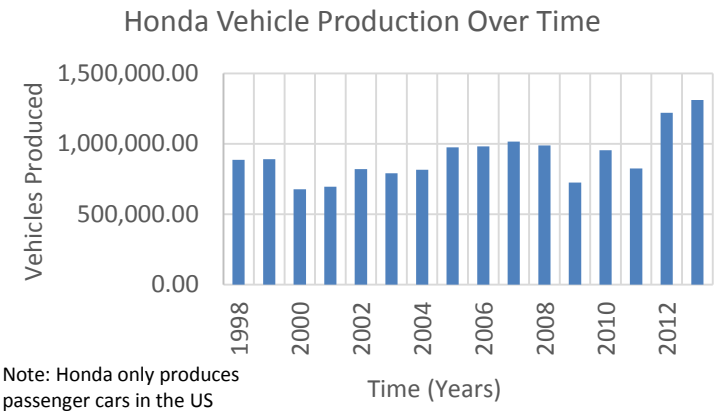
[39] Ibid
[40] OICA. 2014 Production Statistics. <http://www.oica.net/category/production-statistics/>
[41] Ibid
[42] *Contribution of the Automotive Industry to the Economies of All Fifty States and the United States*, Center for Automotive Research, January 2015, p.30
[43] *Id.*

Figure 5-1: Domestic Vehicle Production, by Major Manufacturer

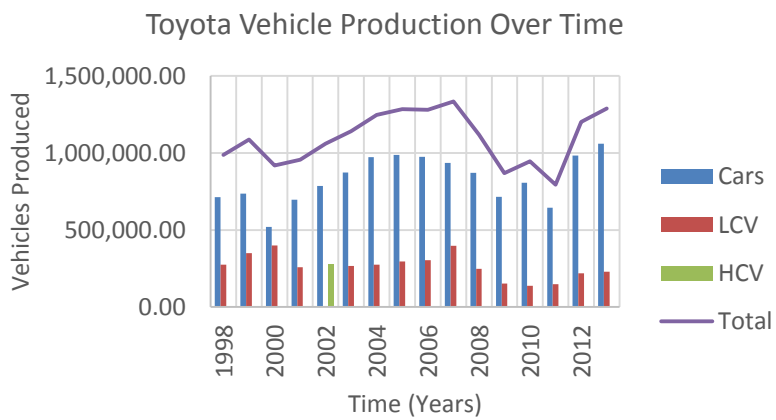


LCV: Light Commercial Vehicles
HCV: Heavy Commercial Vehicles
Note that 1998 and 1999 includes production in both North America and South America.





Note: Honda only produces passenger cars in the US



LCV: Light Commercial Vehicles
HCV: Heavy Commercial Vehicles
Note that 1998 and 1999 includes production in both North America and South America.
Data source: OICA. Production Statistics. <http://www.oica.net/category/production-statistics/2013-statistics>

directly employed by the automotive industry, a large network of people develops around them to provide support services. Think of the doctor or school teacher in a town with an auto manufacturing plant. If that plant shuts down or moves to another location, the support personnel in that town are also in danger of losing their jobs, which has a deadly ripple effect through the local economy.

5.2 Industry Operations Activity in Automotive Manufacturing

Section 5.1 provided an overview of the automotive manufacturing industry. The following sections use the top-down approach discussed in Section 4 to track and discuss automotive manufacturing and its supply chain.

5.2.1 Industry Costs and Labor Hours

The revenue received from the sale of new vehicles is divided between three primary entities: employees, government, and owners/investors. As seen in Table 5-1, the total value added for new vehicles, calculated from the 2007 BEA IO data, associated with the production of new vehicles was $186.3 billion. The values in this table facilitate identifying high resource consumption areas of automobile manufacturing and its supply chain in terms of dollar values. On the far left are industry categories, which for the purpose of this table are aggregated into the 34 categories. The numbers on the left indicate the aggregated NAICS codes used by the BEA. These 34 categories break out into 397 BEA NAICS codes. In the columns labeled A through L are occupation categories. For the purpose of this table, these categories have been aggregated from over 800 to the 12 categories seen in the table. The data in these columns is compensation for that occupation/industry combination contributing to new car production. For example, examining the row with BEA NAICS code 333: machinery manufacturing and the column labeled J: Production Occupations, one can see that $837 million in production occupations in the machinery manufacturing industry contributed to new car production. Column M is the sum of all the compensation costs for that BEA NAICS code. Column N and O are taxes (note that this only includes taxes on imports and production less subsidies) and gross operating surplus. The sum of columns M, N, and O equals value added, as shown in the last column, labeled P. Table 5-1 as a whole breaks out the total value added into various components for the entire US economy that is related to the production of new automobiles, including light trucks, utility vehicles, and heavy duty trucks. The length of the colored bars relate to the value being represented. As the value increases relative to others, the bar lengthens. The bars are compared only to those of the same color.

As seen in Table 5-1 at the bottom right, there is $186.3 billion in value added associated with the production of new automobiles. Approximately 53.6 % of the value added went to compensation of employees, 41.4 % went toward owners/investors, and 5.0 % went to the government in the form of taxes (note that this only includes taxes on imports and production less subsidies). Unsurprisingly, the most costly labor category is production occupations for manufacturing vehicle parts and assembly at $24.3 billion or 13 % of the total value added. The second costliest is management and business occupations for vehicle parts and assembly at $4.9 billion or 2.6 % of the total value added. It is

Table 5-1: Value Added for New Vehicles by Occupation by Industry ($millions)

BEA NAICS	Description	management and business	Computer and Mathematical, and Engineering Occupations	Life, Physical, and Social Science Occupations	Community, legal, education, arts, health, food, and other	Building and Grounds Cleaning and Maintenance Occupations	Sales and Related Occupations	Office and Administrative Support Occupations	Construction and Extraction Occupations	Installation, Maintenance, and Repair Occupations	Production Occupations	Transportation and Material Moving Occupations	Other and Unallocated	Compensation of employees	Taxes on production and imports, less subsidies	Gross operating surplus	Value Added
11	Agriculture, Forestry, Fishing and Hunting	7	0	1	84	1	1	7	1	5	3	21	51	180	-2	233	412
21	Mining, Quarrying, and Oil and Gas Extraction (materials)	13	9	4	1	0	1	5	37	23	15	18	0	125	34	363	522
21	Mining, Quarrying, and Oil and Gas Extraction (non-materials)	69	51	17	6	0	3	14	131	35	19	51	0	397	280	1466	2143
221100-A	Indirect Uses-Boiler Fuel	1	1	0	0	0	0	1	0	2	1	0	0	5	5	10	21
221100-B	Process Heating	7	6	1	1	0	0	3	1	10	6	0	0	35	34	66	136
221100-C	Process Cooling and Refrigeration	3	2	0	0	0	0	1	0	4	2	0	0	14	14	26	54
221100-D	Machine Drive	19	15	2	2	0	1	9	3	28	15	1	0	96	93	181	370
221100-E	Electro-Chemical Processes	2	2	0	0	0	0	1	0	4	2	0	0	13	12	24	49
221100-F	Other Process Use	1	1	0	0	0	0	1	0	2	1	0	0	6	6	11	23
221100-G	Facility HVAC	6	5	1	1	0	0	3	1	9	5	0	0	29	28	55	113
221100-H	Facility Lighting	4	3	0	0	0	0	2	1	6	3	0	0	20	19	38	77
221100-I	Other Facility Support	1	1	0	0	0	0	1	0	2	1	0	0	5	5	10	20
221100-J	Onsite Transportation	1	1	0	0	0	0	1	0	2	1	0	0	7	7	14	28
221100-K	Other Nonprocess Use	0	0	0	0	0	0	0	0	1	0	0	0	2	2	4	9
221100-L	End Use Not Reported	1	1	0	0	0	0	1	0	2	1	0	0	6	5	11	22
22	Energy (non-manufacturing uses) and Utilities	81	49	5	6	1	8	49	25	85	48	6	0	363	277	675	1315
23	Construction	0	0	0	0	0	0	0	0	0	0	0	433	433	10	271	713
336	Manufacturing: Vehicle parts and Assembly	4936	4118	24	172	36	412	1361	1112	2707	24306	1539	0	40722	1154	40278	82153
331	Primary Metal Manufacturing	474	231	10	21	8	73	179	90	427	1790	199	0	3503	241	2832	6576
332	Fabricated Metal Product Manufacturing	955	300	6	12	15	169	407	100	190	2749	173	0	5076	144	2950	8170
333	Machinery Manufacturing	463	385	2	13	4	77	136	25	96	837	41	0	2080	53	1157	3290
334-335	Computer and Electronics Manufacturing	565	726	7	17	3	81	110	4	49	455	30	0	2047	113	1600	3760
324-325	Petroleum and Chemical Manufacturing	248	125	86	10	2	43	74	12	79	412	43	0	1136	147	2974	4258
326	Plastic and Rubber Manufacturing	448	178	11	11	7	89	192	19	204	1441	181	0	2782	152	1163	4097
31-33	Manufacturing: Other	573	152	10	55	10	151	302	75	248	1747	335	0	3658	155	1527	5340
42-45	Wholesale and Retail Trade	2738	688	33	249	25	3748	1672	33	725	382	1467	0	11762	4791	6921	23473
48	Transportation	314	45	1	22	4	51	342	47	239	43	1951	0	3058	179	1682	4918
49	Warehousing	55	6	0	4	4	9	79	1	17	15	227	0	415	8	125	549
518200	Data Processing and Hosting Services	47	81	0	3	0	12	25	0	1	1	0	0	170	8	141	319
51-53	Information, Real Estate, and Finance	1805	397	2	240	22	817	864	9	188	20	43	0	4407	535	5280	10222
54	Professional, Scientific, and Technical Services	1524	1020	82	820	5	195	512	25	20	37	18	0	4258	223	2384	6865
55	Management of Companies	4733	1134	69	444	12	328	1047	34	117	57	96	0	8074	347	1129	9550
56	Admin. And Support and Waste Management and Remediation	462	148	11	307	371	179	525	74	90	158	214	0	2538	77	933	3548
57-92	Other	212	26	2	472	41	58	106	12	234	69	46	1148	2427	105	663	3194
TOTAL		20769	9906	389	2973	573	6510	8031	1874	5851	34640	6702	1632	99851	9262	77195	186307

interesting to note that transportation and material moving occupations for all industries is $6.7 billion or 3.6 % of the total value added. Energy is represented by all of the industries on the left starting with 2211. The total value added of process energy (i.e., the sum of NAICS 221100-A through 221100-F), which represents the energy for manufacturing processes associated with automobile manufacturing, was $652 million or 0.3 % of the total value added. Facility heating, cooling, lighting, and other facility support was $210 million or 0.1 % of the total value added. It is important to note that manufacturing facilities sometimes produce their own electricity. The data that is available facilitates examining this issue, but it has been left for future research.

A key concept of lean manufacturing is the identification of waste, which is classified into seven categories:

1) Overproduction: occurs when more is produced than is currently required by customers
2) Transportation: transportation does not make any change to the product and is a source of risk to the product
3) Rework/Defects: discarded defects result in wasted resources or extra costs correcting the defect
4) Over-processing: occurs when more work is done than is necessary
5) Motion: unnecessary motion results in unnecessary expenditure of time and resources
6) Inventory: is similar to that of overproduction and results in the need for additional handling, space, people, and paperwork to manage extra product
7) Waiting: when workers and equipment are waiting for material and parts, these resources are being wasted

Given these categories of waste, it is interesting to note that wholesale and retail trade, transportation, and warehousing along with transportation and material moving occupations are 18.1 % of the total value added for new automobile production or 30.9 % of costs (excluding depreciation of capital).

Error! Reference source not found. Table 5-2 provides the broadest level of occupation data for new car production while **Error! Reference source not found.** Table 5-3 provides the top 50 of over 800 occupations at the detailed level. As is expected, production occupations account for the largest category at the broadest level. Interestingly, only 6 of the top 20 occupations in Table 5-3**Error! Reference source not ound.**, however, are production occupations. Among the others are occupations within management; transportation and material moving; architecture and engineering; installation, maintenance, and repair; sales; business and finance; and construction and extraction occupations. Industrial machinery mechanics are number 12, suggesting that machinery maintenance and repair is a significant cost. It is important to note that the highest cost activities are not necessarily the highest paid per hour. For example, an hour of management is more than twice as much as an hour of production work, as seen in Table 5-2**Error! Reference source not found.**.

For a more detailed use of this model, we can consider a change agent interested in examining the maintenance, repair, replacement, and energy for machinery associated with new car production. The aggregate compensation for industrial machinery mechanics and machinery maintenance workers for new car production and its supply chain is $1.8 billion with $647.6 million being for automobile assembly alone, as seen in

Table 5-2: Compensation for New Vehicle Production by Occupation, Broad Category Level

Occupation Code and Description		Compensation ($millions)	Hours (millions)	Per hr compensation
510000	Production Occupations	34640.1	984.6	35.2
110000	Management Occupations	13436.8	148.9	90.3
430000	Office and Administrative Support Occupations	8030.6	307.1	26.2
130000	Business and Financial Operations Occupations	7332.5	141.0	52.0
530000	Transportation and Material Moving Occupations	6701.7	255.8	26.2
170000	Architecture and Engineering Occupations	6306.3	100.8	62.6
490000	Installation, Maintenance, and Repair Occupations	5850.8	143.3	40.8
410000	Sales and Related Occupations	6510.0	149.7	43.5
150000	Computer and Mathematical Occupations	3600.0	65.1	55.3
470000	Construction and Extraction Occupations	1874.4	40.8	45.9
270000	Arts, Design, Entertainment, Sports, and Media Occupations	806.0	20.4	39.5
230000	Legal Occupations	802.6	11.0	73.2
370000	Building and Grounds Cleaning and Maintenance Occupations	573.4	39.6	14.5
290000	Healthcare Practitioners and Technical Occupations	406.0	9.8	41.3
190000	Life, Physical, and Social Science Occupations	389.1	8.7	44.6
350000	Food Preparation and Serving Related Occupations	349.8	33.6	10.4
330000	Protective Service Occupations	250.3	14.6	17.1
450000	Farming, Fishing, and Forestry Occupations	138.9	6.2	22.5
390000	Personal Care and Service Occupations	94.5	5.9	15.9
210000	Community and Social Service Occupations	44.1	1.6	27.3
310000	Healthcare Support Occupations	42.3	2.9	14.7
250000	Education, Training, and Library Occupations	38.1	2.1	18.5

Table 5-4. Of the $1.8 billion, $1.5 billion was mechanics while $290.7 million was maintenance workers. An additional $1.2 billion was spent on machinery for new car production and its supply chain. Some of this machinery would be to replace old machinery while some could be to increase capacity. The machinery in place throughout the new car production supply chain consumed $631.2 million in energy with $369.6 million in energy for machine drive (i.e., mechanical energy or motors). Future research efforts will facilitate examining the value of machinery being used.

5.2.2 Time and Building Capital

Time is an important aspect in operations management and understanding the costs of production. Every moment that a product or material sits idle or is in production it is consuming resources. Materials and products in inventory must be stored, cataloged, and protected, taking up building space and real estate. If they are in transit, they are taking up space on trucks, trains, and vehicles. Meanwhile the materials and products themselves tie up capital, depreciate, deteriorate, and become obsolete.

Figure 5-2 provides a summarized version of the steps of manufacturing production categorized into activity in the supply chain based on chronology. At this point these steps are approximated. Future research might provide a more detailed supply chain map,

rather than broad classifications. For example, raw material extraction is in step 1, as it occurs before any of the manufacturing steps. Plastics material and resin manufacturing is categorized in step 2, as it comes after the extraction of raw materials but before plastic product manufacturing in step 3.

Table 5-3: Compensation for New Vehicle Production by Occupation, Top 50 (Detailed Category Level)

Occupation Code and Description		Compensation ($millions)	Hours (millions)	Per hr compensation
512092	Team Assemblers	12905.3	318.7	40.5
111021	General and Operations Managers	4212.5	45.7	92.2
414012	Sales Representatives, Wholesale and Manufacturing, Except Technical and S	3167.9	67.2	47.1
511011	First-Line Supervisors of Production and Operating Workers	2913.0	56.2	51.8
172112	Industrial Engineers	2206.5	30.7	71.8
514041	Machinists	1963.8	58.3	33.7
113051	Industrial Production Managers	1640.7	19.6	83.7
537062	Laborers and Freight, Stock, and Material Movers, Hand	1624.7	72.1	22.5
519061	Inspectors, Testers, Sorters, Samplers, and Weighers	1600.8	47.5	33.7
533032	Heavy and Tractor-Trailer Truck Drivers	1585.7	56.3	28.2
132011	Accountants and Auditors	1463.1	28.8	50.9
499041	Industrial Machinery Mechanics	1460.3	30.2	48.3
172141	Mechanical Engineers	1453.9	21.3	68.3
512099	Assemblers and Fabricators, All Other	1445.7	45.2	32.0
113031	Financial Managers	1230.2	12.9	95.6
499071	Maintenance and Repair Workers, General	1199.2	34.0	35.2
514111	Tool and Die Makers	1195.1	23.8	50.2
434051	Customer Service Representatives	1098.3	44.0	25.0
112022	Sales Managers	1078.3	11.7	92.1
472111	Electricians	954.9	16.6	57.5
119041	Architectural and Engineering Managers	946.1	9.2	102.5
537051	Industrial Truck and Tractor Operators	940.7	30.5	30.8
111011	Chief Executives	920.6	6.5	142.2
514121	Welders, Cutters, Solderers, and Brazers	912.8	31.6	28.9
519199	Production Workers, All Other	890.0	21.7	40.9
439061	Office Clerks, General	839.6	38.5	21.8
414011	Sales Representatives, Wholesale and Manufacturing, Technical and Scientifi	826.8	13.8	60.1
514031	Cutting, Punching, and Press Machine Setters, Operators, and Tenders, Metal	820.3	31.0	26.5
131199	Business Operations Specialists, All Other	796.4	14.9	53.5
435071	Shipping, Receiving, and Traffic Clerks	785.2	30.9	25.4
431011	First-Line Supervisors of Office and Administrative Support Workers	764.2	18.7	40.8
433031	Bookkeeping, Accounting, and Auditing Clerks	754.9	28.1	26.8
514011	Computer-Controlled Machine Tool Operators, Metal and Plastic	748.8	26.5	28.2
131111	Management Analysts	681.1	11.5	59.1
491011	First-Line Supervisors of Mechanics, Installers, and Repairers	671.1	11.7	57.3
151132	Software Developers, Applications	667.5	10.6	62.9
151121	Computer Systems Analysts	657.3	10.9	60.5
231011	Lawyers	653.8	6.7	97.7
113021	Computer and Information Systems Managers	617.1	6.9	89.1
131023	Purchasing Agents, Except Wholesale, Retail, and Farm Products	608.2	12.7	47.7
436014	Secretaries and Administrative Assistants, Except Legal, Medical, and Executi	588.8	25.0	23.5
131161	Market Research Analysts and Marketing Specialists	569.4	11.7	48.6
514081	Multiple Machine Tool Setters, Operators, and Tenders, Metal and Plastic	564.7	19.0	29.7
519198	Helpers--Production Workers	563.1	25.8	21.9
413031	Securities, Commodities, and Financial Services Sales Agents	551.3	4.1	133.1
512031	Engine and Other Machine Assemblers	539.5	13.2	40.8
514072	Molding, Coremaking, and Casting Machine Setters, Operators, and Tenders, N	519.3	20.4	25.5
435081	Stock Clerks and Order Fillers	507.8	22.3	22.7
131071	Human Resources Specialists	495.2	10.8	46.1
119199	Managers, All Other	492.0	6.1	81.0

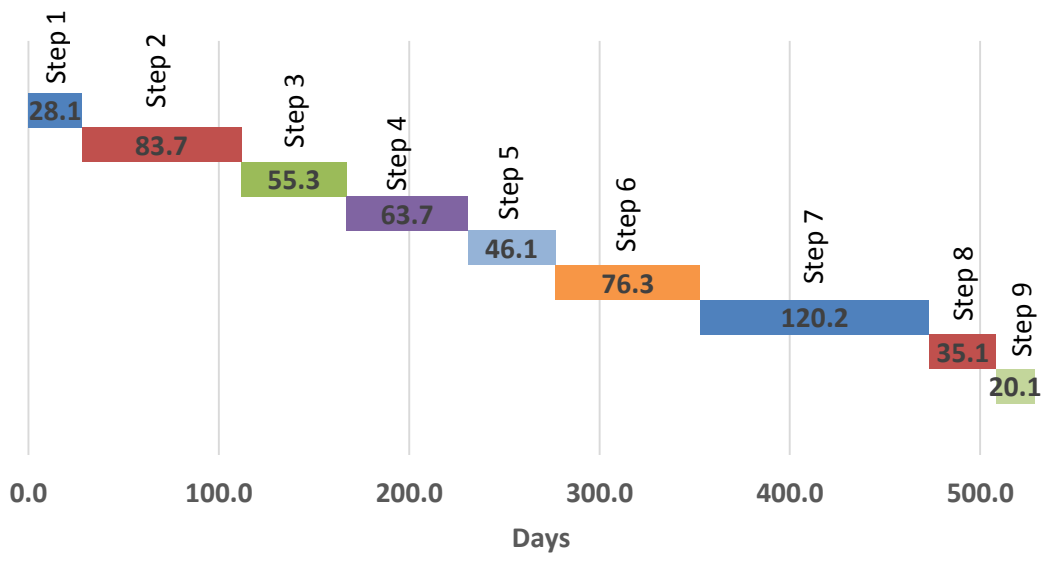
Table 5-4: Machinery Data for New Car Production ($millions)

	Assembly Only	Total Supply Chain for New Cars
Maintenance and Repair	647.6	1751.0
Machinery Mechanics	627.9	1460.3
Machinery Maintenance	19.7	290.7
New Machinery for Production	949.4	1230.0
Other industrial machinery manufacturing	0.0	42.4
Plastics and rubber industry machinery manufacturing	0.0	3.7
Industrial mold manufacturing	13.4	54.9
Metal cutting and forming machine tool manufacturing	0.0	33.6
Special tool, die, jig, and fixture manufacturing	13.8	95.2
Cutting, machine tool, and metalworking machinery	22.6	77.5
Turbine and turbine generator set units manufacturing	0.0	19.4
Speed changer, industrial high-speed drive, and gear	0.0	106.9
Mechanical power transmission equipment manufacturing	508.1	270.4
Pump and pumping equipment manufacturing	0.0	15.6
Air and gas compressor manufacturing	0.0	12.2
Material handling equipment manufacturing	6.1	54.8
Power-driven handtool manufacturing	0.0	3.4
Other general purpose machinery manufacturing	33.3	94.4
Industrial process furnace and oven manufacturing	0.0	6.7
Fluid power process machinery	352.1	339.1
Machine Related Energy	93.7	631.2
Process Heating	7.2	135.6
Process Cooling and Refrigeration	10.9	53.9
Machine Drive	65.2	369.6
Electro-Chemical Processes	0.2	49.1
Other Process Use	10.2	23.0

Table 5-5 presents details of the each of these steps for the top 35 manufacturing subsectors, representing 88 % of the manufacturing value added for new car production. Also included are 5 raw material extractors that are associated with manufacturing. The average time for each step in each industry has been calculated. For instance, material inventory for NAICS 325211 in step 2 has an average time of 10.62 days for material goods inventory. Work-in-process time is 3.71 days, down time when the plant is closed is 0.48 days and finished goods is 25.81 days. A multiplier, discussed previously, was estimated and used to approximate the number of times a material cycled through an industry.

At the bottom of each step in Table 5-5 is the average of all industries in the step. One average includes the multiplier while the other excludes it. For instance, at the bottom of step 2 is the average of the total time in days for the 5 industries in the step. Also shown is the average of the different inventory times, including material inventory, work-in-process inventory, work-in-process down time, and finished goods inventory. The sum of the average for the 9 steps with the multiplier is 528 days and without the multiplier is

Figure 5-2: Supply Chain Steps and Average Flow Time



348 days. Using the data with the multiplier reveals that 42 % of the 528 days is material inventory, work-in-process is 10 %, down time when the plant is closed was 15 %, and finished goods was 33 %.

One of the costs of inventory, whether it is materials, finished goods, or work-in-process, is the cost of housing the inventory. Table 5-6 provides an estimated value of the buildings that house manufacturing activities related to new automobile production. It is the square feet of factory space multiplied by the median per square foot cost of factory construction for a typical sized factory from RS Means.[44]

5.2.3 Natural Resources and Environmental Impacts

Table 5-7 provides the results of the environmental impacts and natural resources used for the top 35 NAICS codes calculated utilizing the data and methods in Sections 3 and 4. As can be seen, glass product manufacturing, iron and steel mills, and automobile manufacturing (i.e., assembly) have some of the highest impacts. Plastic material and resin manufacturing have a high impact on ozone depletion.

[44] RS Means Mechanical Cost Data. (RS Means, Kingston, MA: 2005). 28th Edition. 558.

Table 5-5: Approximated Chronological Supply Chain Steps and Corresponding NAICS Codes for New Vehicle Production

Approximated Step: 1				Approximated Step: 2				Approximated Step: 3			
NAICS	Location	Days		NAICS	Location	Days	Multiplier	NAICS	Location	Days	Multiplier
211000 Oil and gas extraction	Total	8.37		325211 Plastics material and resin manufacturing	Materials	10.62	1.47	326110 Plastics packaging materials and unlaminated film and sheet	Materials	18.43	1.67
					WIP	3.71			WIP	2.59	
					WIP - Down time	0.48			WIP - Down time	3.12	
					Finished Goods	25.81			Finished Goods	21.09	
212100 Coal mining	Total	13.39		325510 Paint and coating manufacturing	Materials	15.76	1.00	326190 Other plastics product manufacturing	Materials	15.48	1.24
					WIP	0.92			WIP	2.25	
					WIP - Down time	1.48			WIP - Down time	1.92	
					Finished Goods	23.69			Finished Goods	19.42	
212230 Copper, nickel, lead, and zinc mining	Total	45.61		327200 Glass and glass product manufacturing	Materials	15.03	2.69	326210 Tire manufacturing	Materials	10.69	1.21
					WIP	2.41			WIP	2.00	
					WIP - Down time	2.32			WIP - Down time	1.70	
					Finished Goods	28.92			Finished Goods	13.72	
2122A0 Iron, gold, silver, and other metal ore mining	Total	38.68		331110 Iron and steel mills and ferroalloy manufacturing	Materials	26.62	2.63	326290 Other rubber product manufacturing	Materials	16.17	1.94
					WIP	8.95			WIP	2.81	
					WIP - Down time	5.37			WIP - Down time	2.63	
					Finished Goods	18.40			Finished Goods	13.20	
2123A0 Other nonmetallic mineral mining and quarrying	Total	34.53		322210 Paperboard container manufacturing	Materials	15.97	1.00	331200 Steel product manufacturing from purchased steel	Materials	34.84	1.07
					WIP	1.41			WIP	9.09	
					WIP - Down time	0.77			WIP - Down time	5.45	
					Finished Goods	11.59			Finished Goods	22.70	
								331510 Ferrous metal foundries	Materials	16.88	1.00
									WIP	4.87	
									WIP - Down time	5.93	
									Finished Goods	19.27	
								331520 Nonferrous metal foundries	Materials	14.17	1.00
									WIP	4.98	
									WIP - Down time	7.44	
									Finished Goods	10.68	
							w/multiplier				w/multiplier
AVERAGES	Total	28.12	28.12	AVERAGES	Materials	16.80	31.57	AVERAGES	Materials	18.09	23.23
					WIP	3.48	7.57		WIP	4.08	4.94
					WIP - Down time	2.08	4.67		WIP - Down time	4.03	4.85
					Finished Goods	21.68	39.89		Finished Goods	17.15	22.25
TOTAL of Averages		28.12	28.12			44.05	83.70			43.36	55.26

Approximated Step: 4				Approximated Step: 5				Approximated Step: 6			
NAICS	Location	Days	Multiplier	NAICS	Location	Days	Multiplier	NAICS	Location	Days	Multiplier
332114 Custom roll forming	Materials	30.83	1.00	332710 Machine shops	Materials	9.86	1.71	332720 Turned product and screw, nut, and bolt manufacturing	Materials	14.43	1.33
	WIP	3.78			WIP	7.74			WIP	5.70	
	WIP - Down time	4.73			WIP - Down time	9.69			WIP - Down time	11.74	
	Finished Goods	16.04			Finished Goods	16.52			Finished Goods	22.67	
33211A All other forging, stamping, and sintering	Materials	24.92	1.95	336370 Motor vehicle metal stamping	Materials	8.64	1.00	332800 Coating, engraving, heat treating and allied activities	Materials	21.23	1.47
	WIP	10.86			WIP	2.80			WIP	2.91	
	WIP - Down time	16.21			WIP - Down time	3.80			WIP - Down time	5.99	
	Finished Goods	14.56			Finished Goods	5.73			Finished Goods	15.18	
33211B Crown and closure manufacturing and metal	Materials	16.13	1.03	336310 Motor vehicle gasoline engine and engine parts	Materials	15.69	1.00	336211 Motor vehicle body manufacturing	Materials	23.00	1.56
	WIP	4.04			WIP	2.90			WIP	7.53	
	WIP - Down time	5.06			WIP - Down time	5.12			WIP - Down time	12.63	
	Finished Goods	17.53			Finished Goods	5.06			Finished Goods	14.43	
332310 Plate work and fabricated structural	Materials	20.80	1.44	336320 Motor vehicle electrical and electronic equipment	Materials	16.47	1.58				
	WIP	7.12			WIP	3.11					
	WIP - Down time	8.91			WIP - Down time	4.22					
	Finished Goods	8.19			Finished Goods	14.00					
334413 Semiconductor and related device	Materials	9.63	2.04								
	WIP	8.69									
	WIP - Down time	16.82									
	Finished Goods	7.87									
			w/multiplier				w/multiplier				w/multiplier
AVERAGES	Materials	20.46	24.28	AVERAGES	Materials	12.66	16.80	AVERAGES	Materials	19.55	28.73
	WIP	6.90	9.52		WIP	4.14	5.96		WIP	5.38	7.86
	WIP - Down time	10.35	14.80		WIP - Down time	5.71	8.03		WIP - Down time	10.12	14.69
	Finished Goods	12.84	15.06		Finished Goods	10.33	15.28		Finished Goods	17.43	24.97
		50.54	63.66			32.84	46.07			52.48	76.26

Approximated Step: 7				Approximated Step: 8				Approximated Step: 9			
NAICS	Location	Days	Multiplier	NAICS	Location	Days	Multiplier	NAICS	Location	Days	Multiplier
33291A Valve and fittings other than plumbing	Materials	28.15	1.71	333618 Other engine equipment manufacturing	Materials	16.01	1.74	336111 Automobile manufacturing	Materials	7.38	1.00
	WIP	6.99			WIP	5.86			WIP	0.68	
	WIP - Down time	14.39			WIP - Down time	7.58			WIP - Down time	1.16	
	Finished Goods	32.03			Finished Goods	14.38			Finished Goods	0.66	
332991 Ball and roller bearing manufacturing	Materials	21.25	3.81	334514 Totalizing fluid meter and counting device manufacturing	Materials	19.05	1.00	336120 Heavy duty truck manufacturing	Materials	15.22	1.00
	WIP	8.18			WIP	2.13			WIP	5.15	
	WIP - Down time	16.83			WIP - Down time	5.18			WIP - Down time	4.17	
	Finished Goods	23.72			Finished Goods	7.16			Finished Goods	5.77	
336360 Motor vehicle seating and interior trim manufacturing	Materials	8.18	2.03	336112 Light truck and utility vehicle manufacturing	Materials	3.71	1.00				
	WIP	0.93			WIP	1.04					
	WIP - Down time	1.26			WIP - Down time	2.33					
	Finished Goods	2.03			Finished Goods	0.85					
336390 Other motor vehicle parts manufacturing	Materials	14.75	1.70	3363A0 Motor vehicle steering, suspension component (except	Materials	15.72	1.00				
	WIP	2.11			WIP	2.41					
	WIP - Down time	2.87			WIP - Down time	3.27					
	Finished Goods	9.83			Finished Goods	11.06					
				336350 Motor vehicle transmission and power train parts	Materials	11.71	1.00				
					WIP	3.49					
					WIP - Down time	4.74					
					Finished Goods	5.32					
			w/multiplier				w/multiplier				w/multiplier
AVERAGES	Materials	18.08	42.64	AVERAGES	Materials	13.24	15.60	AVERAGES	Materials	11.30	11.30
	WIP	4.55	12.13		WIP	2.99	3.85		WIP	2.92	2.92
	WIP - Down time	8.84	24.01		WIP - Down time	4.62	5.74		WIP - Down time	2.66	2.66
	Finished Goods	16.90	41.44		Finished Goods	7.75	9.87		Finished Goods	3.22	3.22
		48.38	120.22			28.60	35.07			20.10	20.10

Table 5-6: Building Capital for New Vehicle Production- New Construction Equivalent, Top 35

NAICS	Description	Building Capital - New Construction Equivalent ($Million 2007)	Percent of Total for Manufacturing
336111	Automobile manufacturing	11460.2	25.9%
336370	Motor vehicle metal stamping	4769.3	10.8%
336350	Motor vehicle transmission and power train parts manufacturing	2577.2	5.8%
336310	Motor vehicle gasoline engine and engine parts manufacturing	1994.4	4.5%
336360	Motor vehicle seating and interior trim manufacturing	1332.5	3.0%
326190	Other plastics product manufacturing	1246.3	2.8%
336390	Other motor vehicle parts manufacturing	1184.9	2.7%
332710	Machine shops	1076.8	2.4%
332720	Turned product and screw, nut, and bolt manufacturing	914.2	2.1%
327200	Glass and glass product manufacturing	903.8	2.0%
3363A0	Motor vehicle steering, suspension component (except spring)	853.5	1.9%
331520	Nonferrous metal foundries	735.6	1.7%
331510	Ferrous metal foundries	706.8	1.6%
331110	Iron and steel mills and ferroalloy manufacturing	689.6	1.6%
336112	Light truck and utility vehicle manufacturing	687.9	1.6%
332800	Coating, engraving, heat treating and allied activities	679.9	1.5%
33211B	Crown and closure manufacturing and metal stamping	669.9	1.5%
333618	Other engine equipment manufacturing	580.2	1.3%
326210	Tire manufacturing	579.9	1.3%
336211	Motor vehicle body manufacturing	503.6	1.1%
326110	Plastics packaging materials and unlaminated film and sheet manufacturing	458.6	1.0%
326290	Other rubber product manufacturing	387.1	0.9%
331200	Steel product manufacturing from purchased steel	364.6	0.8%
33291A	Valve and fittings other than plumbing	358.7	0.8%
332310	Plate work and fabricated structural product manufacturing	321.2	0.7%
322210	Paperboard container manufacturing	310.7	0.7%
336320	Motor vehicle electrical and electronic equipment manufacturing	291.3	0.7%
332991	Ball and roller bearing manufacturing	271.9	0.6%
332320	Ornamental and architectural metal products manufacturing	267.6	0.6%
33211A	All other forging, stamping, and sintering	261.4	0.6%
332114	Custom roll forming	251.3	0.6%
325211	Plastics material and resin manufacturing	237.5	0.5%
325510	Paint and coating manufacturing	236.1	0.5%
334413	Semiconductor and related device manufacturing	235.1	0.5%
334514	Totalizing fluid meter and counting device manufacturing	218.8	0.5%

Table 5-7: Environmental Impact and Natural Resource use (impact per $million) - Top 35 Industries Contributing to New Car Value Added (In order of largest to smallest)

NAICS	Description	Global Warming kg CO2 eq	Acidification H+ moles eq	HH Criteria Air kg PM10 eq	Eutrophication kg N eq	Ozone Depletion Air kg CFC-11 eq	Smog Air kg O3 eq
336112	Light truck and utility vehicle manufacturing	802 235 765	194 595 504	587 351	103 711	1 355	53 003 030
336111	Automobile manufacturing	2 114 796 363	525 749 064	1 614 049	287 995	2 973	147 926 851
336370	Motor vehicle metal stamping	732 139 877	166 226 243	526 996	84 047	924	42 556 932
336350	Motor vehicle transmission and power train parts manufacturing	1 232 063 582	279 729 745	886 843	141 436	1 555	71 615 886
336360	Motor vehicle seating and interior trim manufacturing	289 421 621	65 710 762	208 327	33 224	365	16 823 146
336120	Heavy duty truck manufacturing	1 240 427 971	247 890 318	771 452	127 621	1 301	69 459 487
336310	Motor vehicle gasoline engine and engine parts manufacturing	692 533 419	157 233 928	498 488	79 500	874	40 254 736
336390	Other motor vehicle parts manufacturing	1 450 944 786	329 424 894	1 044 394	166 563	1 831	84 338 746
331110	Iron and steel mills and ferroalloy manufacturing	38 984 497 805	4 944 560 326	17 533 039	2 502 306	4 857	1 389 164 598
3363A0	Motor vehicle steering, suspension component (except spring), and b	390 962 214	88 764 705	281 416	44 881	493	22 725 374
336211	Motor vehicle body manufacturing	1 777 020 988	403 723 417	1 386 932	205 237	1 830	125 560 690
326190	Other plastics product manufacturing	4 554 148 259	1 096 932 901	3 379 992	552 195	14 504	306 544 333
333618	Other engine equipment manufacturing	3 136 953 432	756 669 244	2 549 280	393 635	2 951	216 066 096
332710	Machine shops	1 511 977 787	352 673 949	979 473	154 317	969	85 276 838
332720	Turned product and screw, nut, and bolt manufacturing	1 876 653 636	380 963 776	1 028 861	174 613	3 257	96 952 100
334413	Semiconductor and related device manufacturing	1 134 409 138	329 692 479	708 923	115 752	2 606	63 556 378
327200	Glass and glass product manufacturing	13 645 923 583	5 630 207 582	17 711 038	3 890 598	11 278	2 175 337 088
331520	Nonferrous metal foundries	3 318 964 906	732 299 119	1 935 053	243 110	1 589	135 174 520
331510	Ferrous metal foundries	2 658 825 017	608 266 439	3 811 699	252 149	1 923	147 670 990
336320	Motor vehicle electrical and electronic equipment manufacturing	189 351 061	42 990 577	136 295	21 737	239	11 006 367
332800	Coating, engraving, heat treating and allied activities	2 277 371 969	423 394 416	1 264 666	199 520	5 048	112 858 278
33211B	Crown and closure manufacturing and metal stamping	1 747 512 700	356 474 204	1 021 743	164 367	1 233	92 030 297
326210	Tire manufacturing	1 995 798 942	830 408 681	2 442 000	282 378	5 717	139 422 570
325211	Plastics material and resin manufacturing	7 195 253 685	1 333 799 460	4 778 652	751 231	24 212	410 458 663
325510	Paint and coating manufacturing	1 865 548 246	416 379 330	1 681 113	239 101	5 459	128 715 607
33291A	Valve and fittings other than plumbing	754 904 058	183 943 457	511 322	78 240	679	43 479 777
334514	Totalizing fluid meter and counting device manufacturing	483 665 457	122 150 771	331 135	55 170	758	30 208 452
331200	Steel product manufacturing from purchased steel	4 203 371 779	586 907 238	2 021 036	301 302	940	167 441 851
322210	Paperboard container manufacturing	1 996 303 783	670 334 733	2 258 787	340 137	3 524	177 476 320
326110	Plastics packaging materials and unlaminated film and sheet manufa	1 870 829 612	421 837 468	1 281 353	214 093	6 428	118 325 850
326290	Other rubber product manufacturing	1 142 249 249	347 538 429	1 223 870	148 514	4 139	74 238 553
332310	Plate work and fabricated structural product manufacturing	1 434 558 039	238 128 626	760 714	120 529	2 317	68 679 738
332991	Ball and roller bearing manufacturing	491 274 903	105 214 214	283 090	47 207	494	26 443 272
332114	Custom roll forming	2 048 580 888	346 310 411	1 029 263	167 601	563	93 303 486
33211A	All other forging, stamping, and sintering	1 386 165 121	263 323 702	734 097	119 930	418	66 554 435

NAICS	Description	ecotox CTUe	HH Cancer CTUHcan	HH Noncancer CTUHnoncan	Primary Energy Consumption thousand BTU	Land Use acre	Water Consumption kg
336112	Light truck and utility vehicle manufacturing	333 718 797	0.40	27	6 465 738 811	131 741	51 424 986 126
336111	Automobile manufacturing	963 848 306	1.07	72	17 185 730 319	376 956	141 007 021 487
336370	Motor vehicle metal stamping	282 399 141	0.37	29	5 381 002 265	110 142	41 383 673 418
336350	Motor vehicle transmission and power train parts manufacturing	475 228 448	0.62	48	9 055 287 290	185 350	69 641 496 783
336360	Motor vehicle seating and interior trim manufacturing	111 634 976	0.14	11	2 127 159 644	43 540	16 359 346 396
336120	Heavy duty truck manufacturing	344 883 373	0.51	34	10 991 320 888	191 168	64 662 757 281
336310	Motor vehicle gasoline engine and engine parts manufacturing	267 122 238	0.35	27	5 089 907 014	104 184	39 144 947 208
336390	Other motor vehicle parts manufacturing	559 654 752	0.72	57	10 663 996 623	218 278	82 013 597 440
331110	Iron and steel mills and ferroalloy manufacturing	1 902 159 377	8.10	830	146 261 861 421	571 607	688 401 450 750
3363A0	Motor vehicle steering, suspension component (except spring), and t	150 800 956	0.20	15	2 873 451 679	58 816	22 098 854 455
336211	Motor vehicle body manufacturing	519 867 842	0.91	59	13 868 653 656	321 844	98 849 842 951
326190	Other plastics product manufacturing	959 307 849	2.71	124	46 020 194 901	886 023	268 515 658 354
333618	Other engine equipment manufacturing	643 647 308	1.69	121	25 034 673 908	1 068 271	180 167 334 550
332710	Machine shops	223 471 339	0.72	55	13 130 704 502	85 814	91 952 974 077
332720	Turned product and screw, nut, and bolt manufacturing	196 365 688	0.69	55	12 944 274 005	86 396	90 459 414 229
334413	Semiconductor and related device manufacturing	117 194 467	0.59	48	8 760 769 460	84 520	69 119 590 110
327200	Glass and glass product manufacturing	1 132 907 270	7.22	477	154 297 681 834	1 164 312	606 594 995 472
331520	Nonferrous metal foundries	1 356 465 856	1.90	238	20 390 257 023	163 545	138 138 048 636
331510	Ferrous metal foundries	634 700 522	2.89	255	19 690 102 574	121 681	136 012 010 929
336320	Motor vehicle electrical and electronic equipment manufacturing	73 036 012	0.09	7	1 391 671 891	28 486	10 702 930 829
332800	Coating, engraving, heat treating and allied activities	290 614 108	0.91	68	22 972 741 972	98 776	98 554 442 985
33211B	Crown and closure manufacturing and metal stamping	210 692 539	0.66	54	11 511 334 439	142 878	71 183 142 739
326210	Tire manufacturing	1 566 391 745	1.01	57	18 502 191 646	1 116 950	162 578 160 812
325211	Plastics material and resin manufacturing	1 039 105 436	3.23	134	56 560 178 654	335 253	252 644 823 224
325510	Paint and coating manufacturing	420 891 408	1.11	66	17 736 186 030	169 942	95 342 870 878
33291A	Valve and fittings other than plumbing	162 731 063	0.41	34	5 800 248 178	49 108	43 295 805 641
334514	Totalizing fluid meter and counting device manufacturing	83 625 776	0.28	21	4 341 997 562	47 318	32 633 188 723
331200	Steel product manufacturing from purchased steel	309 088 123	1.11	111	19 058 889 406	95 008	99 319 008 590
322210	Paperboard container manufacturing	381 634 554	1.14	55	22 215 719 096	2 143 098	116 522 959 529
326110	Plastics packaging materials and unlaminated film and sheet manuf	334 319 603	0.85	41	16 432 521 642	170 557	95 487 993 867
326290	Other rubber product manufacturing	555 454 623	0.53	26	10 226 786 393	566 212	87 627 967 095
332310	Plate work and fabricated structural product manufacturing	134 816 245	0.44	43	8 118 987 307	95 127	48 971 352 998
332991	Ball and roller bearing manufacturing	40 513 662	0.17	12	3 776 385 245	21 162	25 851 399 834
332114	Custom roll forming	154 116 144	0.65	59	11 392 952 735	60 046	60 741 397 345
33211A	All other forging, stamping, and sintering	131 496 036	0.50	44	9 918 713 914	42 633	51 172 191 468

6 Summary and Recommendations for Future Research

Advances in efficiency are often achieved through competition among private firms; however, barriers to efficiency improvement can surpass the ability of any single firm. In these situations, publicly-funded research can advance efficiency; however, there is a need to identify the efforts that might have the largest impact per dollar of investment. This report identifies and reviews data on manufacturing activity and provides a model of industry operations activity. The method is described and then illustrated using the automobile manufacturing industry. This method focuses on top down data; however, there was some discussion of bottom up data. Section 6.1 provides a summary of the method and the illustrated case study and Section 6.2 provides recommendations for future research.

6.1 Summary

The final analysis examines automotive manufacturing qualitatively and quantitatively using input-output analysis combined with other industry data to estimate industry operations activity. Using input-output analysis, the proportion of inter-industry interactions is used to estimate the labor and other resources that are dedicated to the specified industry of study, in this case automotive manufacturing. The aggregated dataset layout, illustrated in Table 4-1, is a 1238 by 397 matrix resulting in over 490 000 information points on the US economy with over 290 000 being related to manufacturing. That is, the model provides over 490 000 categories of information covering compensation costs, taxes, gross operating surplus, labor hours, production time, environmental impacts, natural resource use, energy consumption by end use (e.g., heating/cooling and production processes), and building capital. Compensation and other labor related activities are broken into over 800 different occupations for each industry. Industry data is broken into over 300 NAICS code categories for each industry. Environmental and natural resource consumption is broken into 12 TRACI categories for each industry. This model includes the resources used in US manufacturing and its US based supply chain.

The total value added for new vehicles, calculated from the 2007 BEA IO data, associated with the production of new vehicles was $186.3 billion. Approximately 53.6 % of the value added went to compensation of employees, 41.4 % went toward owners/investors, and 5.0 % went to the government in the form of taxes (note that this only includes taxes on imports and production less subsidies). Unsurprisingly, the most costly labor category is production occupations for manufacturing vehicle parts and assembly at $24.3 billion or 13 % of the total value added. The second costliest is management and business occupations for vehicle parts and assembly at $4.9 billion or 2.6 % of the total value added. It is interesting to note that transportation and material moving occupations for all industries is $6.7 billion or 3.6 % of the total value added. The total value added of process energy (i.e., the sum of NAICS 221100-A through 221100-F), which represents the energy for manufacturing processes associated with automobile manufacturing, was $652 million or 0.3 % of the total value added. Facility heating, cooling, lighting, and other facility support was $210 million or 0.1 % of the total value added. Wholesale and retail trade, transportation, and warehousing along with

transportation and material moving occupations from other industries, which are activities that do not alter the final product, is 18.1 % of the total value added for new automobile production or 30.9 % of costs (excluding depreciation of capital).

The model presented also facilitates identifying those areas of production that consume the most resources. Three categories of resources are discussed: time, labor, and natural resources. Labor is categorized by industry by industry by occupation. Time is broken into industry by stage (materials inventory, work in process, work in process down time, and final goods inventory). The final category, natural resources, is broken into industry; however, this category was discussed only briefly. To utilize this model, a change agent might examine the various resources consumed in an area of manufacturing of interest. As was shown focusing on automobile manufacturing, a change agent could identify the areas of highest resource consumption. For example, 'industrial machinery mechanics' is among the highest cost activities. The change agent might focus their efforts in this area. As the model presented in this report develops further, a more formal approach may be developed.

6.2 Recommendations for Future Research

There are two categories of future research: research to advance the accuracy of the model and research to advance the detail of the model. To advance the accuracy there is a need to temporally extend the model. Due to the nature of the data, the model is based on 2007 data; however, data is available on an annual basis that can be used to make estimates for more recent years. These estimates will provide a more up to date analysis while also providing an opportunity to examine how resource use is changing over time. Much of the data provides relative standard error estimates. Using these estimates along with Monte Carlo analysis can provide insight into the error bands for the model. Another potential area of future research is to update the data on environmental impacts and natural resource use. The model currently utilizes 2002 data adjusted to 2007. Updating this data will provide a more accurate estimate.

In addition to research to advance the accuracy of the model, efforts can extend the details of the model. The model is systematically categorized by NAICS, SOC, and other categorization, making it feasible to collect data that augments the model. One potential area for expansion is in transportation. Currently, the four categories of inventory time engulf transportation; therefore, it is not explicitly broken out. Data is available from the Department of Transportation that might break out this detail. On site electricity production is another area that could be expanded. The current model does not estimate the production and end use of this type of electricity, but data is available that would allow such an estimate. For a thorough understanding of time use in the supply chain, it is necessary to chronologically map the industry supply chain using NAICS codes. Currently, the model broke industries into steps and took an average of those steps. Also, the model does not examine the resources expended in the use of the final product. Data is available that might be used to make estimates of the resources consumed for these purposes.

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