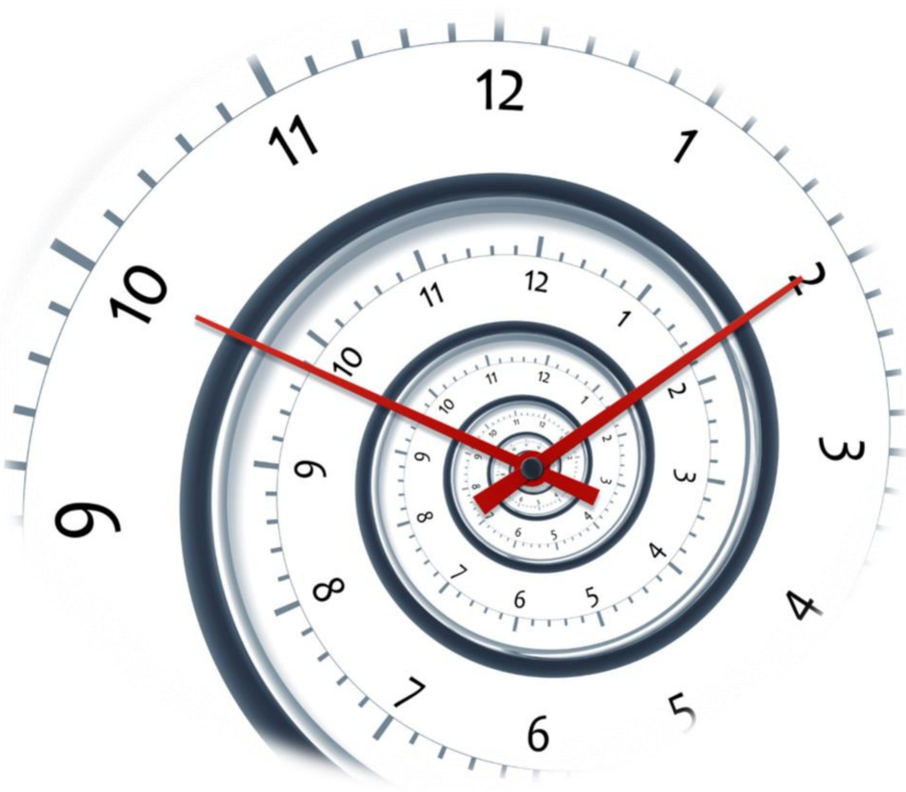
NIST Technical Note 1890

Inventory and Flow Time in the US Manufacturing Industry

Douglas S. Thomas
Anand M. Kandaswamy



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Penny Pritzker, Secretary

National Institute of Standards and Technology
Willie E. May, Under Secretary of Commerce for Standards and Technology and Director of NIST

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Abstract

Advancements in the efficient use of inputs, such as land and labor, have been a key driver of per capita income growth throughout history. One method for identifying potential efficiency improvements is lean manufacturing or lean production, a set of tools to assist in the identification and elimination of waste. Lean classifies waste into seven categories: overproduction, transportation, rework/defects, over-processing, motion, inventory, and waiting. Utilizing economic data, one can track the inventory and transportation time along with the flow time (i.e., the amount of time a unit spends in process), which reveals some of the categories of waste. This report identifies and reviews data on manufacturing inventory and flow time along with data on inter-industry interactions. It then develops a method for tracking the flow time of US manufactured products. This method is illustrated for automotive and aircraft manufacturing.

Keywords: manufacturing; input output; automotive manufacturing; aircraft manufacturing; flow time

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.

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1 Introduction

1.1 Background

Advancements in the efficient use of inputs, such as land and labor, have been a key driver of per capita income growth throughout history. The private sector continuously improves efficiency on its own; however, there are barriers to advancement in some areas that require public resources. These are, typically, instances where the market outcome or allocation of goods and services is not Pareto efficient; that is, it is possible to make one person or entity better off without making another person or entity worse off.

One major barrier to advancement is explored in the book *Public Goods, Public Gains* by the economists Albert N. Link and John T. Scott.[1] The basic idea underlying Link and Scott's thesis is that there are goods and processes where the private hurdle rate, the rate that determines whether one should invest in a project or not, is much higher than the social hurdle rate.[2] Building on the work of senior NIST economist Gregory Tassey and Professor Adam B. Jaffe, Link and Scott show that when the private rate of return does not exceed the private hurdle rate, then innovation is stifled for those cases where the social rate of return is greater than the social hurdle rate. Thus, a great deal of publicly beneficial innovation will not take place, absent a public commitment to funding.

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."[3] A significant focus for NIST is in advancing innovation and industrial competitiveness by improving efficiency in manufacturing. Unfortunately, in a world of scarce resources, there are limited public funds; therefore, the efforts that have the greatest impact per dollar of public investment are prioritized over those with a lower impact per dollar.

One method for identifying potential efficiency improvements is lean manufacturing or lean production, a set of tools to assist in the identification and elimination of waste. Lean classifies waste into seven categories:

1) Overproduction: occurs when more is produced than is currently required by customers
2) Transportation: unnecessary 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

[1] See Tassey, Gregory. 2005. Underinvestment in Public Good Technologies. Journal of Technology Transfer 30: 89-113 and Jaffe, Adam B. 1998. The Importance of 'Spillovers' in the Policy Mission of the ATP. Journal of Technology Transfer 23: 11-19.

[2] Link, Albert N. and John T. Scott. Public Goods, Public Gains: Calculating the Social Benefits of Public R&D. 2011. pp.6-7.

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

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

Utilizing economic data, one can track the inventory and transportation time along with the flow time (i.e., the amount of time a unit spends in process), which can reveal potential categories of waste. Although the data does not break out every category, it does encapsulate the total time for a selected product. For example, flow time does not break out overproduction, rework, or over-processing, but these activities are included in the average flow time.

1.2 Purpose

This report identifies and reviews data on manufacturing inventory and flow time along with data on inter-industry interactions. It then develops a method for tracking the flow time of US manufactured products. This method is illustrated for automotive and aircraft manufacturing.

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 and aircraft manufacturing.

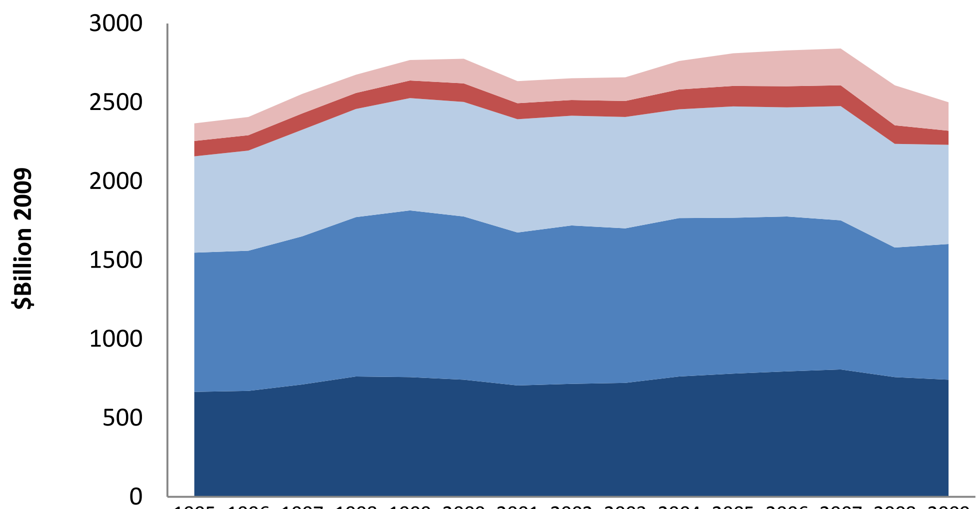
We first discuss the geographic scope of this study and standard data categorization in Section 2. The data and methods are presented in Section 3. It includes a discussion of the Annual Survey of Manufactures and the BEA Benchmark Input-Output data. Also discussed is inventory turns and a proposed industry reiteration rate. Section 4 uses the method discussed and illustrates it for automobile manufacturing and aircraft manufacturing. Section 5 presents a summary and recommendations for future research.

2 Geographic Scope and Standard Data Categorization

2.1 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 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 manufacturing supply chain that is imported. The value added for the U.S. manufacturing industry and its supply chain is presented in Figure 2-1. It should be noted that manufacturing supply chains have their own unique characteristics and performance metrics.[4] The values in the figure progress from top to bottom, starting with foreign activities used in US manufacturing and progressing to domestic activities. 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

Figure 2-1: 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>

[4] Gunasekaran, A., Patel, C., & Tirtiroglu, E., 2001 "Performance measures and metrics in a supply chain environment." International Journal of Operations & Production Management 21, no. 1/2: 71-87.

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 as a percent of all value added associated with that 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. NIST, however, promotes US innovation and industrial competitiveness; therefore, the imported goods and services are outside of the scope of this report.

2.2 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. Standard categorization is critical to tracking resources. Domestic data tends to be in the North American Industry Classification System (NAICS). It is the standard used by Federal statistical agencies since 1997 for 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. 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 2-1 presents the lowest level of detail, which is the two digit NAICS. There are 20 two-digit categories. Additional detail is added by adding additional digits; thus, three digits provides more detail than the two digit codes 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). Aircraft manufacturing is also shown in the table (NAICS 336411). It is still part of NAICS 336, as it is also transportation equipment, but is has a separate four digit NAICS (NAICS 3364). 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.

Table 2-1: 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*
3364	*Aerospace Product and Parts Manufacturing*
33641	*Aerospace Product and Parts Manufacturing*
336411	*Aircraft 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
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

3 Data and Methods

3.1 Data

There are two datasets that are needed to track flow and inventory time in US manufacturing: the Annual Survey of Manufactures from the U.S. Census Bureau and the Bureau of Economic Analysis (BEA) Benchmark Input-Output data. This data is supplemented by a third dataset, the Survey of Plant Capacity Utilization from the Census Bureau. This dataset provides the average hours that factories are operating per week. The following sections discuss these datasets and how they are used in the method.

3.1.1 BEA Benchmark Input-Output Data

Annual input-output data is available from the 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. [5] In 2007, there were 389 industries in the Benchmark data. This data is provided in the form of make and use tables, with their corresponding matrices replacing the Leontief method.[6] 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 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 they 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 the Nobel Prize-winning economist Wassily Leontief, although as noted above, they replace part of the Leontief model.[7] Within this model, economies of scale are ignored; thus, it operates

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

[6] A System of National Accounts, Studies in Methods, Series F/No. 2/Rev. 3, United Nations, New York, 1968.

[7] Guo, Jiemin, Ann M. Lawson, and Mark A. Planting. October 2002. From Make-Use to Symmetric I-O Tables: An Assessment of Alternative Technology Assumptions. <https://www.bea.gov/papers/pdf/alttechassump.pdf>

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

Code	Industry Description	Automobile manufacturing 336111	Light truck and utility vehicle manufacturing 336112	Heavy duty truck manufacturing 336120	…	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	Automobile manufacturing 336111	Light truck and utility vehicle manufacturing 336112	Heavy duty truck manufacturing 336120	…	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**

under constant returns to scale.[8] The model also assumes that a sector uses inputs in fixed proportions. This report uses an industry-by-commodity format as outlined in Horowitz and Planting.[9] 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 Inventory Data

The Annual Survey of Manufactures (ASM) is conducted every year except for when the Economic Census is conducted (i.e., years ending in 2 or 7).[10] 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 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 classifications, as illustrated in Table 3-3; however, prior to NAICS the Standard Industrial Classification system was used.[11] 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

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[8] Lau, Lawrence J. and Shuji Tamura. November-December 1972, Volume 80, No. 6. Economies of Scale, Technical Progress, and the Nonhomothetic Leontief Production Function: As Application to the Japanese Petrochemical Processing Industry. Journal of Poltical Economy.

[9] 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>

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

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

Table 3-3: 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								
⋮	⋮								

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. 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 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."[12]

3.2 Methods

Metrics in operations management often measure the time that it takes to produce a product. These metrics vary in complexity, use, and development.[13] Having too many materials and goods on hand is often considered an indication of a problem, as inventory

[12] 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>
[13] Melnyk, Steven A., Douglas M. Stewart, and Morgan Swink. Metrics and Performance Measurement in Operations Management: Dealing with the Metrics Maze. Journal of Operations Management 22 (2004). pp.209-217.

deteriorates over time, consumes resources to maintain it, and ties up capital. To track the flow time and inventory time, it is necessary to follow the materials used in production from the extraction out of the ground to the final product. The Benchmark Input-output data allows for tracking this. In addition to the inter-industry linkages in the BEA data, two measures are necessary to track the industry time it takes to produce a product: inventory turns and an industry reiteration rate.

3.2.1 Inter-Industry Linkages

The Use table from the BEA Benchmark Input-Output tables provides the items each industry purchases from other industries. This data, however, includes not only the materials, but also the energy, machinery, services, and other items that are not part of the final product. To track the flow time and inventory time, it is necessary to identify only those activities that process materials that are physically part of the final product. To identify these activities, the data from the Use table that applies to manufacturing was extracted. A subset of these items were selected based on their contribution to the industry of interest (e.g., automobile manufacturing and aircraft manufacturing). Using input-output analysis, the items that contributed to the industry of interest were sorted based on the value they contributed. Items were selected from the largest to the smallest until 90 % of the supply chain value was accounted for. Each of these supply chain entities was reviewed along with their supply chain entities. Some were eliminated from the list as they were not part of the final product. Some items were added to the list when they were identified as being a part of the final product, but not originally selected.

3.2.2 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 ("COGS" or "throughput") divided by the average inventory. The throughput is usually stated in yearly terms.[14] Academics use inventory turnover ratios in studying a number of fields, like distributive trade.[15] 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.

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[14] Hopp, Wallace J. and Mark L. Spearman. Factory Physics, Third Edition. 2008. p.230.

[15] Karic, Marijan, Ivan Kristek, and Maja Vidovic. Measuring the Inventory Turnover in Distributive Trade. <ftp://ftp.repec.org/opt/ReDIF/RePEc/osi/bulimm/PDF/BusinessLogisticsinModernManagement13/blimm1308.pdf>

3.2.3 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 3-1. For example, a chemical plant could produce chemical A while another plant produces chemical B from chemical A. A third plant might yet be using chemical B to produce chemical C. Chemical A was processed through three establishments, similar to the flow in Figure 3-1. 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 other establishments 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 0.3 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 0.3 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:

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

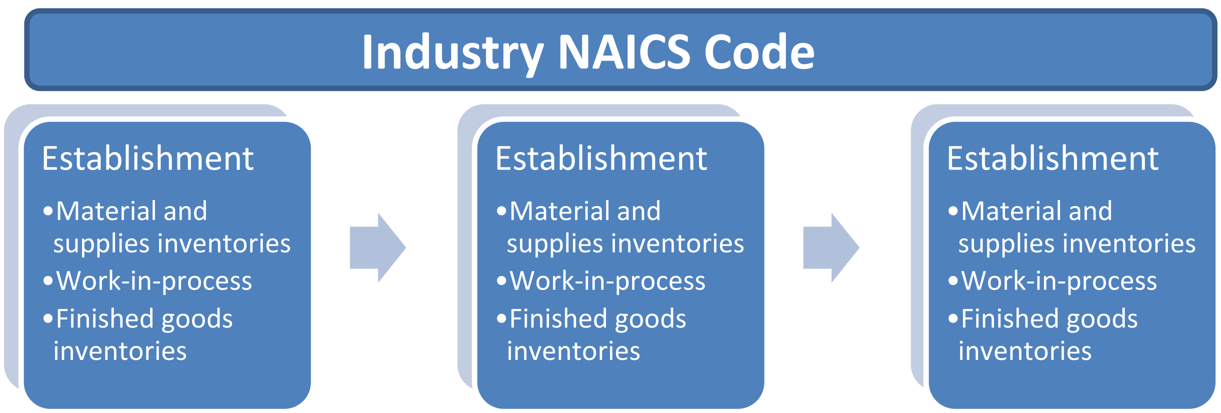
Where
T = The selected threshold, which is between 0 and 1
P = Proportion of materials, parts, containers, packaging, and resales that are purchased from an entity in the same industry.

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 3-1: 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 Two Case Studies: Automobile and Aircraft Manufacturing

This section illustrates the methods discussed in Section 3 for the automobile and aircraft manufacturing industries. These two industries require a myriad of parts and raw materials that results in a complex supply chain.

4.1 Automotive Manufacturing

Final stage automotive manufacturing consists of three primary NAICS codes: 336120 Heavy duty truck manufacturing, 336112 Light truck and utility vehicle manufacturing, and 336111 Automobile manufacturing. These items connect to a series of NAICS codes related to automotive manufacturing:

336370 Motor vehicle metal stamping
336211 Motor vehicle body manufacturing
336310 Motor vehicle gasoline engine and engine parts manufacturing
336320 Motor vehicle electrical and electronic equipment manufacturing
336350 Motor vehicle transmission and power train parts manufacturing
336360 Motor vehicle seating and interior trim manufacturing
336390 Other motor vehicle parts manufacturing
3363A0 Motor vehicle steering, suspension component and brake systems manufacturing

These items were grouped or relabeled into seven categories: body, engine, vehicle electronics, powertrain, interior, other parts, and steering and suspension. The remaining NAICS for automobile manufacturing supply chain entities were grouped into three categories: basic elements, simple intermediate parts, and complex intermediate parts. NAICS codes for basic elements were categorized into seven categories: copper, iron and steel, aluminum, other metals, plastic, rubber, and inorganic chemicals. Simple intermediate parts includes nineteen categories: fabric, carpet, paint, adhesives, other plastic products, tires, hoses and belts, rubber products, glass products, crown and closure, springs and wires, machine shops, screws and nuts, valves and fittings, ball and roller bearings, other metal products, wiring, batteries, and hardware. Complex intermediate parts includes four categories: audio and video, semiconductors, other electronic components, and circuits.

There are numerous flow paths from raw material extraction to the assembled automobile, as seen in Figure 4-1. This figure provides a diagram of all the NAICS code connections selected for automobile manufacturing. It is a complex diagram that is challenging to follow, illustrating the difficulty in tracking supply chains. The longest flow path that was identified for automotive manufacturing was 794.0 days and is traced in Table 4-1. The flow would start in the industry at the top, oil and gas extraction (NAICS 211000), which has an inventory time of 8.4 days. It would then flow to the petroleum refineries (NAICS 324110). It would go through the industry's materials and supplies inventories, work in process, work in process downtime, and finished goods inventory. It would then flow to the next industry, starting again with the materials and supplies inventories. This flow includes inventory and transportation time and is multiplied using the reiteration rate. Oil and gas extraction through plastics material and resin manufacturing accounts for 432.9 days or 54 % of the flow. Work-in-process accounts for only 56.1 days or 7.1 % of the time.[16] Work-in-process down time (i.e., time when the factory is closed) accounts for 72.8 days or 9.3 % of the time. Materials and supplies inventory along with finished goods inventory, which includes transportation, accounts for 83.6 % of the flow.

It is important to note that the determination of these paths is flexible. For example, one might posit that two activities can or do occur parallel to one another rather than in series. Also, the reiteration rate may vary. Appendix A provides a list of the NAICS codes for the automotive flow, including the reiteration rate, work in process time, and various inventory times. This is the time that is spent just in that industry, excluding time the materials spent in the supply chain prior to reaching the industry. The largest reiteration rate is petrochemical manufacturing at 10.4. This rate suggests that petrochemicals go through, on average, 10.4 establishments before leaving the industry. This raises petrochemicals from a 19.8 day flow to a 205.0 day flow. Ball and roller bearing manufacturing is the second largest reiteration rate at 3.8, but this process requires 70.0 days without the reiteration rate. Table 4-2 provides the aggregate flow for each of the categories described for automotive manufacturing.

Table 4-1: Longest Flow Path for Automobile Manufacturing

	Materials and supplies Inventory	Work in Process	Work-in-Process (downtime)	Finished goods Inventory	Total
211000 Oil and gas extraction	-	-	-	-	8.4
324110 Petroleum refineries	7.2	2.3	4.1	10.5	24.1
325110 Petrochemical manufacturing	73.1	7.3	8.9	115.7	205.0
325190 Other basic organic chemical manufacturing	19.2	5.8	2.0	43.0	69.9
325130 Synthetic dye and pigment manufacturing	27.7	4.9	1.7	31.5	65.8
325211 Plastics material and resin manufacturing	15.6	5.5	0.7	37.9	59.7
335930 Wiring device manufacturing	26.9	4.5	7.7	27.6	66.8
334418 Printed circuit assembly manufacturing	51.7	6.9	14.2	13.2	86.0
33441A Other electronic component manufacturing	71.6	13.4	25.7	27.9	138.6
336320 Motor vehicle electrical and electronics manufacturing	26.1	4.9	6.7	22.2	59.8
336111 Automobile manufacturing	7.4	0.7	1.2	0.7	9.9
TOTAL	326.5	56.1	72.8	330.2	794.0

[16] Note that oil and gas extraction is excluded from this calculation as that data is not available

Table 4-2: Aggregate Flow by Automotive Supply Chain Category

Category	Aggregate Flow (Days)	Category	Aggregate Flow (Days)
Automobile Manufacturing	794.0	Tires	458.8
Vehicle electronics	784.1	Plastic	432.9
other electronic components	724.3	Rubber	424.8
audio and video	664.8	Machine shops	397.3
Body	647.4	Screws and nuts	395.1
Engine	617.6	Springs and wires	391.8
Power train	614.1	Other metal products	371.9
Steering and suspension	604.6	Crown and closure	366.6
Ball and roller bearings	588.9	Paint	349.2
circuits	585.7	Adhesives	347.7
Valves and fittings	572.1	Semiconductors	338.4
Hardware	536.6	Other metal	322.6
interior	506.6	Iron and steel	319.2
wiring	499.7	copper	250.4
Rubber products	492.2	aluminum	231.2
Battery	483.4	Glass products	165.5
Other parts	483.0	Carpet	113.2
Other plastic products	481.5	Fabric	109.2
Hoses and belts	473.6		

4.2 Aircraft Manufacturing

Final stage aircraft manufacturing is categorized as NAICS 336411 Aircraft Manufacturing. For the purpose of this report, the supply chain flow for aircraft manufacturing was categorized by four sets: basic elements, simple intermediate, complex intermediate, and aircraft parts. Basic elements includes copper, iron and steel, aluminum, other metal, plastic, rubber, other minerals, other petroleum products, and other chemicals. Simple intermediate includes fabric, carpet, paint, other plastic products, hoses and belts, rubber products, crown and closure, springs and wires, machine shops, screws and nuts, valves and fittings, ball and roller bearings, other metal products, wiring, hardware, carbon and graphite, other stamping, pipes, and refractory. Complex intermediate includes semiconductors, other electronic components, circuits, signal testing, measuring device, wireless communications, navigation and detection, propulsion, plastic sheets, turbine, meters and counting devices, vehicle electronics, power transmission, gears, industrial control, motor and generator, switchgears and switchboards, other engine equipment. Aircraft parts includes aircraft engine, other parts, other aircraft parts. The supply chain is mapped in Figure 4-2.

The final stage, aircraft assembly, alone takes 194.5 days on average with 66.8 days being work in process. Supply chain NAICS codes for aircraft manufacturing were selected in a similar manner as that for automotive manufacturing. Each of the associated NAICS codes are listed in Appendix B. The longest flow path is shown in Table 4-3, which amounts to 1853.4 days or a little over 5 years from raw material extraction to

Figure 4-1: Automobile Manufacturing Supply Chain

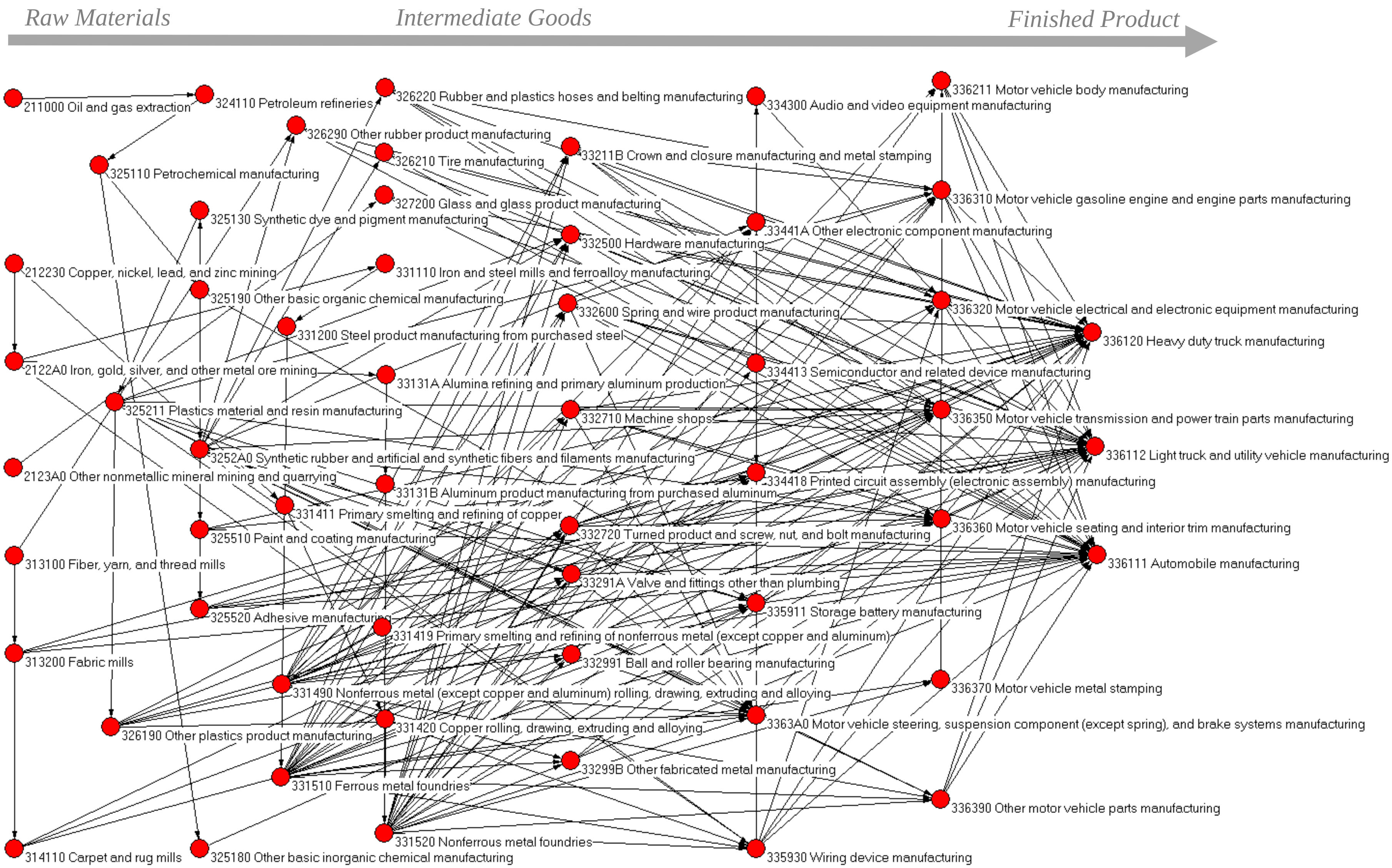
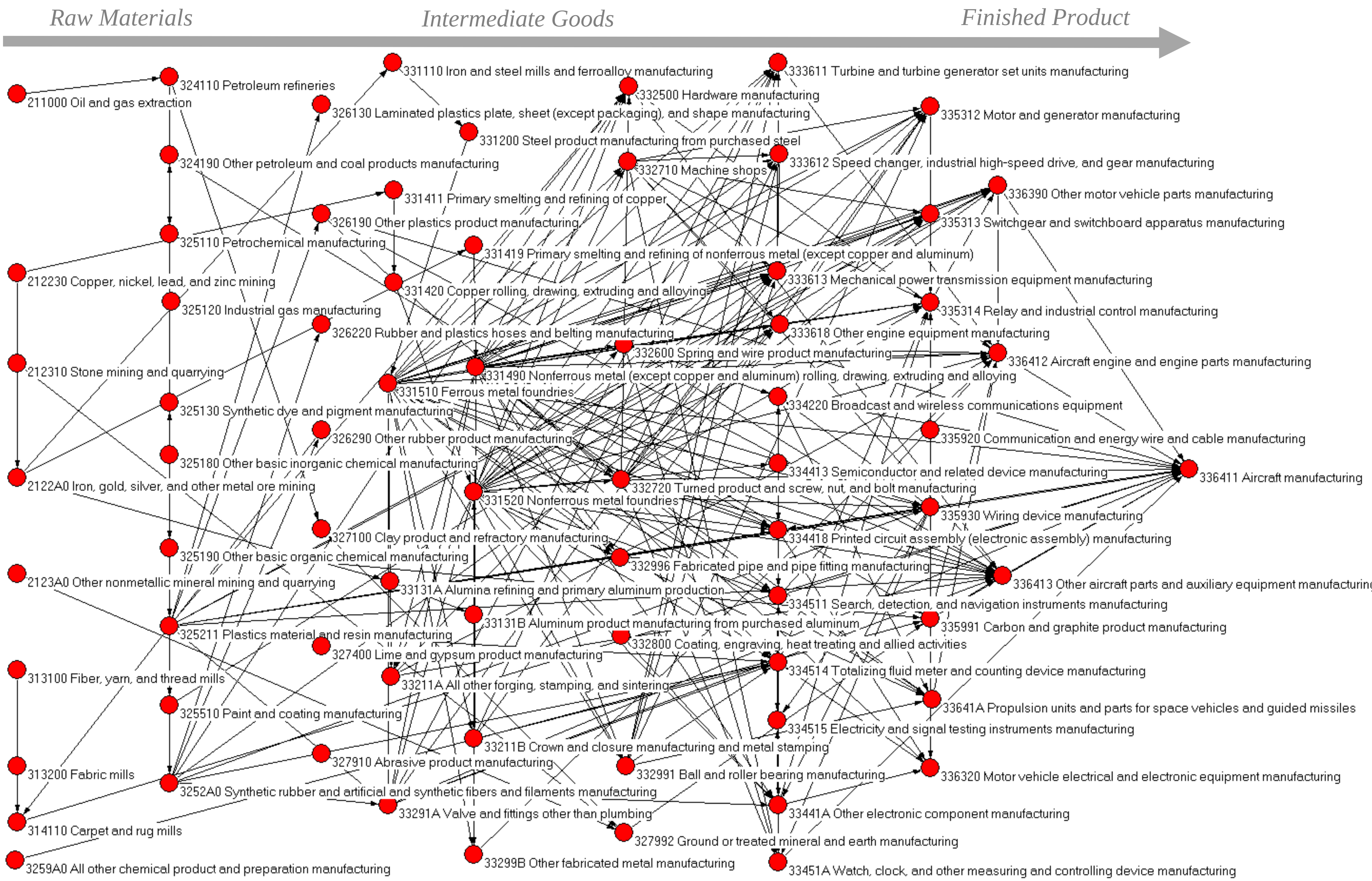


Figure 4-2: Aircraft Manufacturing Supply Chain



final assembly. Aircraft manufacturing is longer than automotive due to additional complexity resulting in additional industry activity. It is also due to the fact that aircraft assembly requires 66.8 days of work in process while automotive assembly only requires 0.7 days. It should be noted that work-in-process time also includes practices such as testing, which for aircraft assembly is extensive. Approximately 359.9 days are spent in work in process or 19.5 % of the total with an additional 459.5 days or 24.9 % in downtime when the factory is closed.[17] Approximately 56.2 % of the time materials are in inventory or transportation. The task of reducing flow time in aircraft manufacturing has occupied both industry professionals and academics.[18] Table 4-4 provides the aggregate flow for the categories for aircraft manufacturing and its supply chain entities.

Table 4-3: Longest Flow Path for Aircraft Manufacturing

BEA NAICS Code and Description	Finished goods	Materials and supplies	WIP	WIP: Downtime	Total
211000 Oil and gas extraction					8.4
324110 Petroleum refineries	10.5	7.2	2.3	4.1	24.1
325110 Petrochemical manufacturing	115.7	73.1	7.3	8.9	205.0
325190 Other basic organic chemical manufacturing	43.0	19.2	5.8	2.0	69.9
325130 Synthetic dye and pigment manufacturing	31.5	27.7	4.9	1.7	65.8
325211 Plastics material and resin manufacturing	37.9	15.6	5.5	0.7	59.7
335930 Wiring device manufacturing	27.6	26.9	4.5	7.7	66.8
334418 Printed circuit assembly manufacturing	13.2	51.7	6.9	14.2	86.0
33441A Other electronic component manufacturing	27.9	71.6	13.4	25.7	138.6
334220 Broadcast and wireless communications equipment	44.0	63.9	50.6	127.1	285.6
33641A Propulsion units and parts for space vehicles	37.7	27.5	88.5	81.4	223.7
336412 Aircraft engine and engine parts manufacturing	104.5	121.8	103.6	95.3	425.3
336411 Aircraft manufacturing	19.2	18.0	66.8	90.6	194.5
TOTAL	512.8	524.3	359.9	459.5	1853.4

[17] Note that this calculation excludes oil and gas extraction.
[18] For example, see Jackson S. Chao and Stephen C. Graves. Reducing Flow Time in Aircraft Manufacturing. <http://web.mit.edu/sgraves/www/papers/chaograves/chaograves.htm#impact> and Roger Schmenner. "The Merit of Making Things Fast." Sloan Management Review, Fall 1988, pp.11-17.

Table 4-4: Aggregate Flow by Aircraft Supply Chain Category

Category	Aggregate Flow (Days)	Category	Aggregate Flow (Days)
Aircraft assembly	1853.4	Other plastic products	481.5
Aircraft engine	1658.9	Hoses and belts	473.6
Propulsion	1233.6	Other engine equipment	473.5
Navigation and detection	1060.3	Carbon and graphite	459.6
Wireless communications	1009.9	Other stamping	452.5
Measuring device	1008.0	Plastic	432.9
Other parts	989.9	Pipes	430.8
Industrial control	939.7	Rubber	424.8
Turbine	932.3	Refractory	413.8
Other aircraft parts	932.1	Machine shops	397.3
Signal testing	911.8	Screws and nuts	395.1
Meters and counting devices	817.6	Springs and wires	391.8
Power transmission	792.0	Other metal products	371.9
Vehicle electronics	784.1	Crown and closure	366.6
other electronic components	724.3	Paint	349.2
Gears	679.6	Semiconductors	338.4
Ball and roller bearings	588.9	Other metal	322.6
circuits	585.7	Iron and steel	319.2
Motor and generator	574.4	Other chemicals	307.4
Valves and fittings	572.1	Other petroleum products	282.2
Hardware	536.6	copper	250.4
wiring	499.7	Other mineral	234.9
Rubber products	492.2	aluminum	231.2
Plastic sheets	483.5	Carpet	113.2
Switchgears and switchboards	483.3	Fabric	37.5

5 Summary and Recommendations for Future Research

5.1 Summary

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.[19] It is in these types of situations that publicly-funded research efforts are often necessary for advancing industry efficiency. This report identifies and reviews data on manufacturing inventory and flow time along with data on inter-industry interactions. It then develops a method for tracking the flow time of US manufactured products. The method developed is illustrated for the automotive and aircraft manufacturing industries.

5.2 Recommendations for Future Research

There are three categories of future research: research to advance the accuracy of the model, research to advance the detail of the model, and using the model to examine other industries. 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, which relies on repeated random sampling, can provide insight into the error bands for the model.[20]

In addition to advancing accuracy, efforts can also extend the detail of this method. 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. For a thorough understanding of time use in the supply chain, it is necessary to map the industry supply chain for each final product using NAICS codes. Currently, only two industries were examined. Also, future data collection might begin to supplement the model to estimate overproduction, rework/defects, over-processing, and waiting, which constitutes 4 of the 7 lean manufacturing categories of waste.

Finally, the model can be applied to other industries to reveal areas of potential efficiency improvements. This might include additional reports such as this one or it might include a tool that users can use to examine industry activity themselves.

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[19] For more on lack of effective communication in the manufacturing process, see "Communication Barriers to Effective Manufacturing" in Manufacturing Systems: Foundations of World-Class Practice. Committee on Foundations of Manufacturing, National Academy of Engineering. 1992. pp.176-179.
[20] Heffernan, Randy. "Monte Carlo and Manufacturing" in Quality Magazine. April 1, 2014. <http://www.qualitymag.com/articles/91769-monte-carlo-and-manufacturing>

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Appendix A: Inventory and Flow Time (Days): Automotive Manufacturing

Below is the inventory and flow time for each stage of each industry (without the reiteration rate) associated with automobile manufacturing. A material going through a particular industry would go through each stage (materials and supplies, WIP, WIP: downtime, and finished goods).

BEA NAICS Code and Description	Reiteration Rate	Materials and supplies	WIP	WIP: Downtime	Finished goods	Total	Total with Reiteration
332991 Ball and roller bearing manufacturing	3.8	21.2	8.2	16.8	23.7	70.0	266.3
325110 Petrochemical manufacturing	10.4	7.1	0.7	0.9	11.2	19.8	205.0
334300 Audio and video equipment manufacturing	2.7	35.1	1.2	2.9	21.3	60.3	165.1
331110 Iron and steel mills and ferroalloy manufacturing	2.6	26.6	8.9	5.4	18.4	59.3	156.2
33291A Valve and fittings other than plumbing	1.7	28.2	7.0	14.4	32.0	81.6	139.3
33441A Other electronic component manufacturing	2.4	30.1	5.6	10.8	11.7	58.3	138.6
33441A Other electronic component manufacturing	2.4	30.1	5.6	10.8	11.7	58.3	138.6
331490 Nonferrous metal (except copper and aluminum) rolling, drawing, extruding and alloying	1.8	24.1	16.3	19.8	16.3	76.5	134.4
327200 Glass and glass product manufacturing	2.7	15.0	2.4	2.3	28.9	48.7	131.0
33211A All other forging, stamping, and sintering	2.0	24.9	10.9	16.2	14.6	66.5	130.0
331419 Primary smelting and refining of nonferrous metal (except copper and aluminum)	2.4	16.8	5.8	7.1	13.6	43.4	103.9
332500 Hardware manufacturing	2.0	18.1	6.5	8.1	18.9	51.7	103.8
325180 Other basic inorganic chemical manufacturing	2.3	14.3	4.9	1.7	20.3	41.2	94.5
336211 Motor vehicle body manufacturing	1.6	23.0	7.5	12.6	14.4	57.6	89.8
331420 Copper rolling, drawing, extruding and alloying	2.8	7.8	4.7	5.8	13.7	31.9	89.7
334413 Semiconductor and related device manufacturing	2.0	9.6	8.7	16.8	7.9	43.0	87.9
334418 Printed circuit assembly (electronic assembly) manufacturing	1.9	27.8	3.7	7.7	7.1	46.3	86.0
332430 Metal can, box, and other metal container (light gauge) manufacturing	2.0	15.2	2.0	2.5	22.1	41.8	82.7
33131A Alumina refining and primary aluminum production	2.2	20.3	5.0	1.8	8.7	35.8	80.3
313300 Textile and fabric finishing and fabric coating mills	1.7	17.6	4.2	3.6	19.6	45.0	78.3
331411 Primary smelting and refining of copper	3.2	2.6	12.5	4.5	4.9	24.5	77.8
331200 Steel product manufacturing from purchased steel	1.1	34.8	9.1	5.5	22.7	72.1	77.3
326110 Plastics packaging materials and unlaminated film and sheet manufacturing	1.7	18.4	2.6	3.1	21.1	45.2	75.4
33131B Aluminum product manufacturing from purchased aluminum	1.8	12.3			9.0	42.4	74.9

332710 Machine shops	1.7	9.9	7.7	9.7	16.5	43.8	74.7
332720 Turned product and screw, nut, and bolt manufacturing	1.3	14.4	5.7	11.7	22.7	54.5	72.5
313200 Fabric mills	1.3	15.9	11.3	3.2	24.6	55.1	71.7
325190 Other basic organic chemical manufacturing	2.0	9.7	2.9	1.0	21.9	35.5	69.9
332600 Spring and wire product manufacturing	1.3	18.5	3.2	4.0	26.6	52.4	69.2
326290 Other rubber product manufacturing	1.9	16.2	2.8	2.6	13.2	34.8	67.3
335930 Wiring device manufacturing	1.2	22.4	3.8	6.4	23.0	55.6	66.8
332800 Coating, engraving, heat treating and allied activities	1.5	21.2	2.9	6.0	15.2	45.3	66.5
325130 Synthetic dye and pigment manufacturing	1.0	27.7	4.9	1.7	31.5	65.8	65.8
332310 Plate work and fabricated structural product manufacturing	1.4	20.8	7.1	8.9	8.2	45.0	64.7
335920 Communication and energy wire and cable manufacturing	1.6	12.2	3.3	5.5	18.8	39.7	62.8
336320 Motor vehicle electrical and electronic equipment manufacturing	1.6	16.5	3.1	4.2	14.0	37.8	59.8
325211 Plastics material and resin manufacturing	1.5	10.6	3.7	0.5	25.8	40.6	59.7
332320 Ornamental and architectural metal products manufacturing	1.3	21.2	3.2	6.6	13.3	44.3	56.1
332114 Custom roll forming	1.0	30.8	3.8	4.7	16.0	55.4	55.4
3252A0 Synthetic rubber and artificial and synthetic fibers and filaments manufacturing	1.0	13.9	4.5	1.4	31.8	51.7	51.7
335911 Storage battery manufacturing	1.0	9.8	9.7	16.5	14.5	50.5	50.5
336390 Other motor vehicle parts manufacturing	1.7	14.7	2.1	2.9	9.8	29.5	50.2
33299B Other fabricated metal manufacturing	1.0	22.6	3.8	7.8	15.1	49.3	49.3
326220 Rubber and plastics hoses and belting manufacturing	1.0	16.5	2.5	3.1	26.7	48.8	48.8
326190 Other plastics product manufacturing	1.2	15.5	2.2	1.9	19.4	39.1	48.6
331510 Ferrous metal foundries	1.0	16.9	4.9	5.9	19.3	46.9	46.9
33211B Crown and closure manufacturing and metal stamping	1.0	16.1	4.0	5.1	17.5	42.8	44.0
325510 Paint and coating manufacturing	1.0	15.8	0.9	1.5	23.7	41.8	41.8
314110 Carpet and rug mills	1.0	15.8	4.2	4.3	17.2	41.5	41.5
325520 Adhesive manufacturing	1.0	16.7	1.3	2.5	19.8	40.3	40.3
326140 Polystyrene foam product manufacturing	1.0	14.1	1.9	1.6	21.6	39.2	39.2
313100 Fiber, yarn, and thread mills	1.3	9.9	4.1	2.6	11.9	28.5	37.5
331520 Nonferrous metal foundries	1.0	14.2	5.0	7.4	10.7	37.3	37.3
326150 Urethane and other foam product (except polystyrene) manufacturing	1.0	18.4	2.5	2.2	11.5	34.6	34.6
326210 Tire manufacturing	1.2	10.7	2.0	1.7	13.7	28.1	34.0
335912 Primary battery manufacturing	1.0	13.4	6.0	10.2	3.9	33.4	33.4
3363A0 Motor vehicle steering, suspension component (except spring), and brake systems manufacturing	1.0	15.7	2.4	3.3	11.1	32.5	32.5
336120 Heavy duty truck manufacturing	1.0	15.2	5.1	4.2	5.8	30.3	30.3
336310 Motor vehicle gasoline engine and engine parts manufacturing	1.0	15.7	2.9	5.1	5.1	28.8	28.8
336350 Motor vehicle transmission and power train parts manufacturing	1.0	11.7	3.5	4.7	5.3	25.3	25.3

336360 Motor vehicle seating and interior trim manufacturing	2.0	8.2	0.9	1.3	2.0	12.4	25.1
324110 Petroleum refineries	1.0	7.2	2.3	4.1	10.5	24.1	24.1
336370 Motor vehicle metal stamping	1.0	8.6	2.8	3.8	5.7	21.0	21.0
336111 Automobile manufacturing	1.0	7.4	0.7	1.2	0.7	9.9	9.9
336112 Light truck and utility vehicle manufacturing	1.0	3.7	1.0	2.3	0.9	7.9	7.9
211000 Oil and gas extraction						8.4	
212100 Coal mining						13.4	
212230 Copper, nickel, lead, and zinc mining						45.6	
2122A0 Iron, gold, silver, and other metal ore mining						38.7	
2123A0 Other nonmetallic mineral mining and quarrying						34.5	

Appendix B: Inventory and Flow Time (Days): Aircraft Manufacturing

Below is the inventory and flow time for each stage of each industry (without the reiteration rate) associated with aircraft manufacturing. A material going through a particular industry would go through each stage (materials and supplies, WIP, WIP: downtime, and finished goods).

BEA NAICS Code and Description	Reiteration Rate	Materials and supplies	WIP	WIP: Downtime	Finished goods	Total	Total with Reiteration Rate
336412 Aircraft engine and engine parts manufacturing	7.7	15.8	25.9	12.4	13.6	55.3	425.3
336413 Other aircraft parts and auxiliary equipment manufacturing	2.9	27.6	72.0	34.5	23.6	123.2	360.0
334220 Broadcast and wireless communications equipment	4.7	13.6	37.8	27.1	9.4	60.8	285.6
332991 Ball and roller bearing manufacturing	3.8	21.2	25.0	16.8	23.7	70.0	266.3
33641A Propulsion units and parts for space vehicles and guided missiles	7.1	3.9	23.8	11.4	5.3	31.3	223.7
325110 Petrochemical manufacturing	10.4	7.1	1.6	0.9	11.2	19.8	205.0
327992 Ground or treated mineral and earth manufacturing	2.9	34.0	10.5	6.4	22.4	66.8	195.5
336411 Aircraft manufacturing	1.1	17.0	148.6	85.6	18.1	183.7	194.5
334515 Electricity and signal testing instruments manufacturing	2.8	32.7	16.1	11.4	17.3	66.1	187.5
327100 Clay product and refractory manufacturing	2.3	22.5	8.3	4.0	46.4	77.2	178.9
327910 Abrasive product manufacturing	3.1	18.2	19.9	12.2	19.8	57.9	177.6
331110 Iron and steel mills and ferroalloy manufacturing	2.6	26.6	14.3	5.4	18.4	59.3	156.2
333611 Turbine and turbine generator set units manufacturing	1.6	55.4	23.3	15.4	7.9	86.7	140.3
33291A Valve and fittings other than plumbing	1.7	28.2	21.4	14.4	32.0	81.6	139.3
33441A Other electronic component manufacturing	2.4	30.1	16.4	10.8	11.7	58.3	138.6
331490 Nonferrous metal (except copper and aluminum) rolling, drawing, extruding and alloying	1.8	24.1	36.1	19.8	16.3	76.5	134.4
33211A All other forging, stamping, and sintering	2.0	24.9	27.1	16.2	14.6	66.5	130.0
335314 Relay and industrial control manufacturing	1.9	29.3	17.8	11.2	16.7	63.8	122.1
333613 Mechanical power transmission equipment manufacturing	1.8	17.0	19.6	11.0	27.5	64.2	112.4
332996 Fabricated pipe and pipe fitting manufacturing	1.6	34.0	14.9	10.0	18.0	67.0	108.2
331419 Primary smelting and refining of nonferrous metal (except copper and aluminum)	2.4	16.8	13.0	7.1	13.6	43.4	103.9
332500 Hardware manufacturing	2.0	18.1	14.7	8.1	18.9	51.7	103.8
335312 Motor and generator manufacturing	1.7	26.9	13.3	8.4	20.7	61.0	101.0
33399B Fluid power process machinery	1.4	26.9	20.5	13.5	23.6	70.9	100.4

33351B Cutting and machine tool accessory, rolling mill, and other metalworking machinery manufacturing	1.4	18.5	26.8	17.7	23.7	69.0	98.3
33451A Watch, clock, and other measuring and controlling device manufacturing	1.2	35.2	19.4	13.7	25.8	80.3	96.1
325180 Other basic inorganic chemical manufacturing	2.3	14.3	6.6	1.7	20.3	41.2	94.5
333612 Speed changer, industrial high-speed drive, and gear manufacturing	1.1	24.7	30.7	17.3	29.4	84.8	90.7
33399A Other general purpose machinery manufacturing	1.2	23.7	30.5	20.0	20.3	74.5	90.0
331420 Copper rolling, drawing, extruding and alloying	2.8	7.8	10.5	5.8	13.7	31.9	89.7
334413 Semiconductor and related device manufacturing	2.0	9.6	25.5	16.8	7.9	43.0	87.9
334418 Printed circuit assembly (electronic assembly) manufacturing	1.9	27.8	11.3	7.7	7.1	46.3	86.0
33131A Alumina refining and primary aluminum production	2.2	20.3	6.8	1.8	8.7	35.8	80.3
331411 Primary smelting and refining of copper	3.2	2.6	17.0	4.5	4.9	24.5	77.8
331200 Steel product manufacturing from purchased steel	1.1	34.8	14.5	5.5	22.7	72.1	77.3
3259A0 All other chemical product and preparation manufacturing	1.6	19.6	7.9	4.3	20.6	48.0	76.3
333618 Other engine equipment manufacturing	1.7	16.0	13.4	7.6	14.4	43.8	76.2
335991 Carbon and graphite product manufacturing	1.0	23.5	28.3	17.8	24.1	75.9	75.9
326110 Plastics packaging materials and unlaminated film and sheet manufacturing	1.7	18.4	5.7	3.1	21.1	45.2	75.4
33131B Aluminum product manufacturing from purchased aluminum	1.8	12.3	21.1		9.0	42.4	74.9
332710 Machine shops	1.7	9.9	17.4	9.7	16.5	43.8	74.7
332720 Turned product and screw, nut, and bolt manufacturing	1.3	14.4	17.4	11.7	22.7	54.5	72.5
313200 Fabric mills	1.3	15.9	14.5	3.2	24.6	55.1	71.7
325190 Other basic organic chemical manufacturing	2.0	9.7	3.9	1.0	21.9	35.5	69.9
332600 Spring and wire product manufacturing	1.3	18.5	7.3	4.0	26.6	52.4	69.2
326290 Other rubber product manufacturing	1.9	16.2	5.4	2.6	13.2	34.8	67.3
335930 Wiring device manufacturing	1.2	22.4	10.2	6.4	23.0	55.6	66.8
332800 Coating, engraving, heat treating and allied activities	1.5	21.2	8.9	6.0	15.2	45.3	66.5
325130 Synthetic dye and pigment manufacturing	1.0	27.7	6.6	1.7	31.5	65.8	65.8
332310 Plate work and fabricated structural product manufacturing	1.4	20.8	16.0	8.9	8.2	45.0	64.7
33712A Other household nonupholstered furniture	1.0	26.8	5.8	4.3	31.8	64.4	64.4
335920 Communication and energy wire and cable manufacturing	1.6	12.2	8.8	5.5	18.8	39.7	62.8
336320 Motor vehicle electrical and electronic equipment manufacturing	1.6	16.5	7.3	4.2	14.0	37.8	59.8
325211 Plastics material and resin manufacturing	1.5	10.6	4.2	0.5	25.8	40.6	59.7
332114 Custom roll forming	1.0	30.8	8.5	4.7	16.0	55.4	55.4
334511 Search, detection, and navigation instruments manufacturing	1.0	10.2	35.4	25.1	6.8	52.3	52.3
3252A0 Synthetic rubber and artificial and synthetic fibers and filaments manufacturing	1.0	13.9	5.9	1.4	31.8	51.7	51.7
333511 Industrial mold manufacturing	1.2	10.5	22.2	13.7	9.1	41.8	50.7
326130 Laminated plastics plate, sheet (except packaging), and shape manufacturing	1.0	23.4	7.6	3.5	19.6	50.6	50.6
335313 Switchgear and switchboard apparatus manufacturing	1.1	20.3	11.6	7.3	12.5	44.5	50.4

336390 Other motor vehicle parts manufacturing	1.7	14.7	5.0	2.9	9.8	29.5	50.2
33299B Other fabricated metal manufacturing	1.0	22.6	11.6	7.8	15.1	49.3	49.3
325910 Printing ink manufacturing	1.0	22.4	2.9	2.0	24.0	49.3	49.3
326220 Rubber and plastics hoses and belting manufacturing	1.0	16.5	5.6	3.1	26.7	48.8	48.8
326190 Other plastics product manufacturing	1.2	15.5	4.2	1.9	19.4	39.1	48.6
331510 Ferrous metal foundries	1.0	16.9	10.8	5.9	19.3	46.9	46.9
324190 Other petroleum and coal products manufacturing	1.0	17.0	5.2	2.8	22.6	44.8	44.8
33211B Crown and closure manufacturing and metal stamping	1.0	16.1	9.1	5.1	17.5	42.8	44.0
325510 Paint and coating manufacturing	1.0	15.8	2.4	1.5	23.7	41.8	41.8
314110 Carpet and rug mills	1.0	15.8	8.5	4.3	17.2	41.5	41.5
313100 Fiber, yarn, and thread mills	1.3	9.9	6.8	2.6	11.9	28.5	37.5
331520 Nonferrous metal foundries	1.0	14.2	12.4	7.4	10.7	37.3	37.3
323120 Support activities for printing	1.5	6.7	9.0	5.8	8.1	23.8	35.4
334514 Totalizing fluid meter and counting device manufacturing	1.0	19.1	7.3	5.2	7.2	33.5	33.5
322210 Paperboard container manufacturing	1.0	16.0	2.2	0.8	11.6	29.7	29.7
325120 Industrial gas manufacturing	1.1	7.8	4.8	0.3	14.0	26.7	28.9
322130 Paperboard mills	1.0	17.6	0.9	0.1	9.7	28.3	28.3
327400 Lime and gypsum product manufacturing	1.0	17.6	1.1	0.3	8.8	27.4	27.4
336360 Motor vehicle seating and interior trim manufacturing	2.0	8.2	2.2	1.3	2.0	12.4	25.1
324110 Petroleum refineries	1.0	7.2	6.4	4.1	10.5	24.1	24.1
2122A0 Iron, gold, silver, and other metal ore mining						38.7	
212100 Coal mining						13.4	
212230 Copper, nickel, lead, and zinc mining						45.6	
2123A0 Other nonmetallic mineral mining and quarrying						34.5	
211000 Oil and gas extraction						8.4	
212310 Stone mining and quarrying						39.5	