Identifying High Resource Consumption Supply Chain Points: A Case Study in Automobile Production

Douglas Thomas, Anand Kandaswamy, and Joshua Kneifel

Abstract: The Pareto principle posits that roughly 80 % of a problem is due to 20 % of the causes, allowing for the targeting of specific efficiency solutions. This paper examines whether the resources used in production are consistent with this principle and then seeks to develop a method to identify those supply chain entities that account for a disproportionally high level of resource consumption compared to other supply chain entities. A novel multi-factor approach is used where resources examined include time, cost, labor, environmental impact, and depreciable assets. The method utilizes data from the BEA 2007 Benchmark make and use tables, Annual Survey of Manufactures, Survey of Plant Capacity Utilization, Manufacturing Energy Consumption Survey, RS Means construction cost data, and an environmentally extended Input-Output database for Life Cycle Assessment (LCA). The approach facilitates the identification of economy-wide opportunities for efficiency improvement in manufacturing, a topic that has limited research devoted to it. Those production activities that consume high levels of resources provide a strong opportunity for efficiency improvement, affecting multiple stakeholders. This method is illustrated by examining automobile manufacturing as a case study. The results suggest that the cost distribution is consistent with the Pareto principle where 20 % of supply chain entities account for 89 %, 89 %, and 91 % of value added, labor hours, and environmental impacts from automobile manufacturing, respectively. Additionally, sixteen supply chain entities were above the 90th percentile in value added, environmental impact, and labor hours for automobile manufacturing, implying efficiency improvements could be obtained across multiple resources simultaneously. For those supply chain entities that would, traditionally, be considered a supplier (i.e., those that manufacture intermediate parts, components, and materials as opposed to those that provide services), the environmental impact, flow time, labor hours, and depreciable assets were above the 90th percentile for one supply chain entity and an additional two are above the 80th percentile.

1. Introduction

To achieve economy-wide efficiency improvements, researchers have suggested that "the supply chain must become the focus of policy management, in contrast to the traditional emphasis on single technologies/industries." [1] System-level inefficiencies can result from companies working independently from one another, such as through the "bullwhip effect" where variations in demand are magnified through a supply chain.[2, 3] Another issue lies in the location of supply chain entities. Manufacturers individually decide on the location of production, but individual decisions may not result in an efficient national supply chain arrangement. Firm level analyses of data can also be a source of inefficiencies, as this can hide economy-wide impacts. For example, a firm might conclude that their transportation cost represents a small portion of their total; however, it is reasonable to expect that they would not consider their suppliers' transportation costs included in material purchases. The result is that the true cost of transportation through the manufacturing life-cycle may not be examined at the firm level.

One of the economic benefits of efficiency and productivity improvements in production is long term economic growth and increases in per capita income.[4] The US is among the highest per capita GDP

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[1] Tassey, Gregory. "Rationales and Mechanisms for Revitalizing US Manufacturing R&D Strategies." *Journal of Technology Transfer*. 35(2010). 283-333.

[2] Lee, H. L., P. Padmanabhan, and S. Whang. The Bullwhip Effect in Supply Chains. Sloan Management Review. 38 (1997): 93-102.

[3] Bray, Robert L. and Haim Mendelson. Management Science. "Information Transmission and the Bullwhip Effect: An Empirical Investigation." (March 2012): 860-875. http://dx.doi.org/10.1287/mnsc.1110.1467

[4] Weil, David N. Economic Growth. United States: Pearson Education Inc., 2005. 181

countries in the world[5] and to maintain this high level of income, the US must continue to advance efficiency and productivity in its economy. However, as factory level and individual supply chain level efficiency improvements are exhausted, it will become necessary to further examine production issues that span across establishments, industries, and supply chains. As a whole, the US has experienced a slowdown in productivity since 2004, resulting in GDP being $2.7 trillion less than it might be otherwise.[6] With a multitude of products, processes, and activities, a holistic approach will require a systematic method to examine production across these factors. The standard categorization of labor and industry activity combined with Input-output analysis, which was originally developed by economist Wassily Leontief,[7] provides a foundation for such an approach. Input-output models are typically used to estimate the impact of a shift in demand for a good or service, but they also provide information on inter-industry activity, making such models an invaluable resource for industry-by-industry resource use within the US economy.

A frequently invoked axiom posits that roughly 80 % of a problem can be traced to 20 % of the cause(s), a phenomenon referred to as the Pareto principle. [8] This paper examines whether the costs and resources used in production are consistent with Pareto's principle, with a small fraction of the supply chain accounting for most of the resource consumption. It then seeks to advance the identification of those supply chain entities that account for a disproportionally high level of resource consumption. A method is developed and used to examine automobile manufacturing as a case study. Automobile manufacturing represents a large industry with many intermediate parts and components, making it a favorable case study for examining the supply chain. A multi-factor approach is used where five measures of resource consumption are examined: material flow time, cost measured in value added, labor cost, environmental impact, and gross depreciable assets. The statistical dispersion of value added, labor hours by industry, labor hours by occupation, and environmental impacts is measured using the Gini coefficient. The purpose of this approach is to facilitate the identification of economy-wide opportunities for efficiency improvement in manufacturing. Those production activities that consume high levels of resources provide a strong opportunity for efficiency improvement affecting multiple stakeholders. Public entities, trade organizations, and other change agents that seek to maximize efficiency improvement through innovative solutions must prioritize their efforts to get the largest reduction per expenditure dollar. It is important to note that there are a number of factors that are relevant to choosing the most economical investments to improve efficiency. The approach in this paper is a tool for examining one of those factors.

2. Methods

This paper uses input-output data and analysis to examine various aspects of the supply chain for manufacturing. Figure 1 illustrates the supply chain analysis being conducted. Industries are categories of establishments (i.e., physical locations of economic activity) based on the product being produced and the processes being used. Commodities (i.e., products and services) are exchanged between industries and are also delivered to the final consumer. For a particular finished commodity, in this case automobiles, a number of values are estimated: the amount of value added from each industry, the total cost of labor by

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[5] World Bank. GDP Per Capita, PPP. 2011-2015. Accessed September 2016. http://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD?order=wbapi_data_value_2014+wbapi_data_value+wbapi_data_value-last&sort=desc.

[6] Syverson, Chad. "Challenges to Mismeasurement Explanations for the US Productivity Slowdown." National Bureau of Economic Research. Working Paper 21974. Accessed September 2016. http://www.nber.org/papers/w21974

[7] Miller, Ronald E. and Peter D. Blair. Input-Output Analysis: Foundations and Extensions. Second Edition. New York: Cambridge University Press, 2009.

[8] Hopp, Wallace J. and Mark L. Spearman. Factory Physics. Third Edition. Long Grove, IL: Waveland Press, 2008. 674.

occupation, the environmental impact from each industry, the value of associated gross depreciable assets from each industry, and the time it takes for a material to move through an industry (note that this flow time measure is only applicable to industries that handle materials). Flow time and the gross value of depreciable assets relate to the use of capital such as machinery and buildings. These two measures are only available for supply chain entities that are within the manufacturing industry. Thus, industries such as transportation and mining will be examined using value added, labor hours, and environmental impact. Labor is analyzed as the sum of a particular labor category needed from all industries to produce a commodity, in this case automobiles (e.g., the sum of the red labor category from Industry A, B, and C to produce the finished commodity shown in Figure 1). The five measures together identify supply chain entities where multiple types of resources are being consumed at high levels. Below is a description of how the estimates are calculated. The methods in this paper build on those in Thomas and Kandaswamy (2016)[9], Thomas and Kandaswamy (2016)[10], and Thomas and Kneifel (2016).[11]

2.1. Industry Flow Time

Time is an important metric for measuring the use of capital because an increase in the time needed for production increases the necessary capital. This paper does not track the flow of physical goods *directly*, but rather tracks the flow of costs, which parallels the flow of physical goods. [12] This paper uses the term flow time, which might also be referred to as throughput time: the time that elapses between buying raw materials for the production process and selling the finished product.[13]

The calculation for flow time can be thought of as water flowing through a hose into a bucket. The cost of goods sold, $COGS$, is the total amount of water that runs into the bucket over a period of time. The inventory values are the amount of water in the hose at any given time. Since we know the total amount of water that flowed out of the hose (i.e., the amount in the bucket or $COGS$), we can estimate how many times the hose was filled and emptied over that period of time (inventory turns) by dividing the amount in the bucket by the volume of the hose. This method makes the assumption of first-in first-out (FIFO), where the oldest goods on hand are sold first.[14] The proposed method for estimating the sum of the flow time for materials and supplies inventories, work-in-process inventories, and finished goods inventories for a particular NAICS code is:

Equation 1

$$FT_{IND,Total} = \sum_{i=1}^{N} IRR_{IND} \times \frac{(INV_{IND,i,BOY} + INV_{IND,i,EOY})/2}{(INV_{IND,Total,BOY} + INV_{IND,Total,EOY})/2} \times \frac{365}{TRN_{IND,Total}}$$

[9] Thomas, Douglas and Anand Kandaswamy. "Identifying High Resource Consumption Areas of Assembly-Centric manufacturing in the United States." National Institute of Standards and Technology. White paper. 2016.

[10] Thomas, Douglas and Anand Kandaswamy. "Improving Manufacturing Efficiency through Supply-Chain Flow Time." National Institute of Standards and Technology. White paper. 2016.

[11] Thomas, Douglas and Joshua Kneifel. "Identifying Environmental Impact Hotspots of Assembly-Centric Manufacturing in the US." National Institute of Standards and Technology. White paper. 2016.

[12] Meigs, Robert F. and Walter B. Meigs. Accounting: The Basis for Business Decisions. 9th edition. New York, NY: McGraw-Hill Inc., 1993. 991.

[13] Horngren, Charles T, Walter T. Harrison Jr., Linda Smith Bamber. Accounting. 5th edition. Upper Saddle River, NJ: Prentice Hall, 2002. 773.

[14] Meigs and Meigs, 409.

Where

$FT_{IND,Total}$ = Total estimated flow time for industry IND

i = Inventory item where i is materials and supplies (MS), work-in-process (WIP), or finished goods (FG) inventories.

$INV_{IND,Total,BOY}$ = Total inventory (i.e., materials and supplies, work-in-process, and finished goods inventories) for industry IND at the beginning of the year

$INV_{IND,Total,EOY}$ = Total inventory (i.e., materials and supplies, work-in-process, and finished goods inventories) for industry IND at the end of the year

$TRN_{IND,Total}$ = Inventory turns for industry IND (defined below)

IRR_{IND} = Industry reiteration rate for industry IND (defined below)

The days that a dollar spends in each of the inventory categories is being calculated by taking the total number of days in a year and dividing it by the number of inventory turns TRN, which is the number of times inventory is sold or used in a time period such as a year (see below). This is then multiplied by average inventory of type N divided by the total inventory. The product in the equation is adjusted by an industry reiteration rate IRR, which is an estimate of the number of times a material is processed in one industry (see below). Finally, the summation of all types of inventory is calculated for industry IND. Work-in-process inventories can be broken into two categories: 1) work-in-process and 2) work-in-process downtime when the factory is closed. The analysis of time flow will focus on work-in-process, as this is the time spent on production. This calculation is discussed below.

Inventory Turns: Inventory turns, TRN_{Total}, is the number of times inventory is sold or used in a time period such as a year.[15, 16, 17] It is calculated as the cost of goods sold (COGS), which is the cost of the inventory that businesses sell to customers,[18] divided by the average inventory:

Equation 2

$$TRN_{Total} = \frac{COGS}{\left(\frac{INV_{Total,BOY} + INV_{Total,EOY}}{2}\right)}$$

Where

$COGS = AP + FB + MAT + DEP + RP + OTH + \left(INV_{Total,BOY} - INV_{Total,EOY}\right)$

AP = Annual payroll

FB = Fringe benefits

[15] Horngren, Harrison, Smith, and Bamber, 186.
[16] Stickney, Clyde P. and Paul R. Brown. Financial Reporting and Statement Analysis. Mason, OH: Southwestern, 1999. 136-137.
[17] Hopp and Spearman. 230.
[18] Horngren, Harrison, Smith, and Bamber, 168.

MAT = Total cost of materials

DEP = Depreciation

RP = Rental payments

OTH = Total other expenses

Inventory turns is usually stated in yearly terms and is used to study a number of fields, such as distributive trade, particularly with respect to wholesaling.[19] The data for calculating $COGS$ is from the Annual Survey of Manufactures. In the previous two equations, inventories are calculated using the average of the beginning of year inventories and end of year inventories, which is standard practice.[20]

Industry Reiteration Rate: The reiteration rate is an estimate of the number of times a material is processed in one industry. A material may go through more than one establishment in an industry. For example, a chemical plant could produce chemical A while another plant produces chemical B from chemical A. Both establishments are in the same industry because they both make chemicals, which would mean that the materials were in inventory approximately twice as long as would be calculated using only the inventory data from the Annual Survey of Manufactures (ASM). One can calculate the number of establishments a material goes through before it is diminished below a certain threshold using a logarithmic function with base P, which is the industry reiteration rate:

Equation 3

$$IRR = log_p T$$

Where

$IRR =$ Industry reiteration rate

P = Proportion of materials, parts, containers, packaging, and resales that are purchased

from an establishment in the same industry (defined below).

T = The selected threshold, which is between 0 and 1. The threshold represents the level of P 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 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 those industries that are below the threshold, the reiteration rate is simply 1. The result is that the IRR is greater than or equal to one.

Two datasets are used to estimate P: the BEA Benchmark Input-Output Use data 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 total cost of materials, parts, containers, and packaging used as well as the cost of resales, which are items purchased and resold without being altered. The inter-industry purchases are divided by the sum of the cost of materials, parts, containers, and packaging used and the cost of resales.[21] This provides P, a proportion of material purchases from the same industry:

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[19] Hopp and Spearman. 230.

[20] Horngren, Harrison, and Bamber. 725, 186.

[21] Resales include items bought and sold in the same condition.

Equation 4

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

This is an average proportion of materials purchased from another establishment 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.

The industry reiteration rate makes the basic assumption that establishments in an industry have similar P values because they compete against each other in producing similar products. As a material moves from one establishment to another, a proportion P of the material moves on to an establishment in the same industry. A proportion of that proportion then moves on to another establishment within the same industry. The log function estimates how many of these proportions a material goes through before it is diminished below the selected threshold by estimating to what power P must be raised to equal T. 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:

$$IRR = log_{0.5} 0.125 = 3$$

This suggests that, given this threshold, a material is likely to go through around three establishments in industry X, on average.

It must be noted that this is a proxy 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 a proxy. Although the industry reiteration rate is not a precise measurement, it creates a multiplier that increases as an industry purchases more goods from itself relative to its purchases from other industries. It also provides a rate that can be compared between industries.

For the analysis, 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. The selected threshold should be appropriate for all industries, as it is applied to all the manufacturing industries in the supply chain. 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.

Work-in-Process Downtime: Flow time for work-in-process inventories (FT_{WIP}) consists of two components: the time that a good is in work-in-process while the factory is open and the time that a good is in work-in-process while the factory is closed. Separating the two out is useful for understanding where the flow time occurs. The time when the factory is closed can be estimated by multiplying the total flow time for work in process by the ratio of total hours that the plant is open:

Equation 5

$$FT_{WIPD} = \left(1 - \frac{Hr_{Plnt}}{168}\right) \times FT_{WIP}$$

Where:

FT_{WIPD} = Flow time for work-in-process downtime when the factory is closed

Hr_{Plnt} = Average plant hours per week in operation from the quarterly Survey of Plant Capacity Utilization

FT_{WIP} = Flow time for work-in-process

Breaking the flow time for work-in-process into time when the factory is open and closed aids in understanding the activities that are occurring during flow time.

The calculations for tracking flow time, FT, can be made for any individual NAICS code category. Materials flow from establishments in one NAICS code to establishments in another NAICS code. These movements can be traced using Input-Output data from the BEA. The Use table from the BEA Benchmark Input-Output tables provides the items each industry purchases from other industries, which was used to create a supply chain map. 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 from NAICS code to NAICS code, 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 by examining the NAICS code descriptions and activities.

2.2. Environmental Impact

The measure of environmental impact is calculated using input-output analysis combined with TRACI 2 impact categories and the Analytical Hierarchy Process to weight the categories. A description of the calculations is below.

Input-Output Analysis: The Make-Use tables are used for Input-Output analysis.[22] The model operates under constant returns to scale and thus ignores potential economies of scale. [23] The model also assumes that a sector uses inputs in fixed proportions. These issues are, typically, relevant to analyses that examine the impact of a change in demand.[24] This paper is not seeking to predict the impact of a change in demand, but rather seeks to track the total resources used for the production of particular goods; therefore, ignoring economies of scale and assuming sectors use inputs in fixed proportions has minimal impact on this analysis. This paper also uses an industry-by-commodity Input-Output format as outlined in Horowitz and Planting (2006), which accounts for the fact that an industry may produce more than one commodity or product, such as secondary products and by-products.[25, 26, 27]

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[22] Miller. 135-138.
[23] Ibid., 16.
[24] Horowitz, Karen J. and Mark A. Planting. Concepts and Methods of the US Input-Output Accounts. Bureau of Economic Analysis. September 2006. <http://www.bea.gov/papers/pdf/IOmanual_092906.pdf>
[25] Ibid.
[26] Miller. 184.
[27] European Commission. Eurostat Manual of Supply, Use, and Input-Output Tables. 2008 Edition. 2008. Accessed September 2016. http://ec.europa.eu/eurostat/documents/3859598/5902113/KS-RA-07-013-EN.PDF/b0b3d71e-3930-4442-94be-70b36cea9b39?version=1.0.

An input-output analysis develops a total requirements matrix that when multiplied by the vector of final demands equals the output needed for production. The total requirements matrix is developed using the methods outlined in Horowitz and Planting (2006):

Equation 6

$$X = W(I - BW)^{-1} * Y$$

Where:

$X =$ Vector of output required to produce final demand

$Y =$ Vector of final demand

$W = (I - \hat{p})D$

$B = U\hat{g}^{-1}$

$I =$ Identity matrix

$D = V\hat{q}^{-1}$

$p =$ A column vector in which each entry shows the ratio of the value of scrap produced in each industry to the industry's total output.

$U =$ Intermediate portion of the use matrix in which the column shows for a given industry the amount of each commodity it uses—including noncomparable imports, scrap, and used and secondhand goods. This is a commodity-by-industry matrix.

$V =$ Make matrix, in which the column shows for a given commodity the amount produced in each industry. This is an industry-by-commodity matrix. V has columns showing only zero entries for noncomparable imports and for scrap.

$g =$ A column vector in which each entry shows the total amount of each industry's output, including its production of scrap. It is an industry-by-one vector.

$q =$ A column vector in which each entry shows the total amount of the output of a commodity. It is a commodity-by-one vector.

$\widehat{\ }$ A symbol that when placed over a vector indicates a square matrix in which the elements of the vector appear on the main diagonal and zeros elsewhere.

In Equation 6, a total requirements matrix $W(I - BW)^{-1}$ is multiplied by a vector of final demand for commodities Y to estimate the total output X. All variables in Equation 6 have known values in the input output data. The output X required to produce an alternate level of final demand can be calculated by altering the final demand vector from the actual final demand Y in the input output data to Y'. For this analysis, Y' has the actual final demand for assembly-centric commodities and zero for other commodities. This alteration reveals the output needed to produce only assembly-centric commodities.

Environmental Impact Categories: The TRACI 2 impact categories are each an aggregation of multiple emissions converted to a common physical unit. For example, the global warming impact category includes impacts of many pollutants, such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (NO_X), and fluorinated gases, which are converted to their carbon dioxide equivalent (CO_2e) impact and aggregated to estimate the total impact for that impact category. The environmental impacts are measured in terms of the common physical unit per dollar of output. The impact can be calculated by multiplying the output in the Input-Output analysis by the impact categories.

Impact Category Weights: Having 12 environmental impact categories makes it difficult to rank industry environmental activity; therefore, the 12 impact categories have been combined into a single environmental metric using the Analytical Hierarchy Process (AHP). AHP is a mathematical method for developing weights using normalized eigenvalues. It involves making pairwise comparisons of competing items based on a multilevel hierarchy developed by the user. The weights used in this paper were developed for the BEES software and can be seen in Table 1.[28] This paper uses 12 of the 13 impact categories for which weights were developed. Indoor Air Quality (IAQ) is excluded because it is more applicable to the design of buildings and ventilation systems rather than to manufacturing activities. The weight of IAQ is proportionally allocated to the other 12 impact categories. The final metric for each industry or industry/commodity combination is the proportion of the total impact from assembly-centric products. The percent of environmental impacts, based on the weights, are calculated using the following equation:

Equation 7

$$\begin{aligned} Env_{z,Y'} = {} & \frac{x_{z,Y'} * GWP_z}{\sum_{i=1}^{n} x_{i,Y'} * GWP_i} * 0.30 + \frac{x_{z,Y'} * Acid_z}{\sum_{i=1}^{n} x_{i,Y'} * Acid_i} * 0.03 + \frac{x_{z,Y'} * HHA_z}{\sum_{i=1}^{n} x_{i,Y'} * HHA_i} * 0.09 \\ & + \frac{x_{z,Y'} * Eut_z}{\sum_{i=1}^{n} x_{i,Y'} * Eut_i} * 0.06 + \frac{x_{z,Y'} * OD_z}{\sum_{i=1}^{n} x_{i,Y'} * OD_i} * 0.02 + \frac{x_{z,Y'} * Sm_z}{\sum_{i=1}^{n} x_{i,Y'} * Sm_i} * 0.04 \\ & + \frac{x_{z,Y'} * Eco_z}{\sum_{i=1}^{n} x_{i,Y'} * Eco_i} * 0.07 + \frac{x_{z,Y'} * HHC_z}{\sum_{i=1}^{n} x_{i,Y'} * HHC_i} * 0.08 + \frac{x_{z,Y'} * HHNC_z}{\sum_{i=1}^{n} x_{i,Y'} * HHNC_i} * 0.05 \\ & + \frac{x_{z,Y'} * PE_z}{\sum_{i=1}^{n} x_{i,Y'} * PE_i} * 0.10 + \frac{x_{z,Y'} * LU_z}{\sum_{i=1}^{n} x_{i,Y'} * LU_i} * 0.06 + \frac{x_{z,Y'} * WC_z}{\sum_{i=1}^{n} x_{i,Y'} * WC_i} * 0.08 \end{aligned}$$

Where

$Env_{z,Y'} =$ Environmental impact from industry z for final demand Y'

$GWP_z =$ Global warming potential per dollar of output for industry z

[28] Lippiatt, Barbara, Anne Landfield Greig, and Priya Lavappa. Building for Environmental and Economic Sustainability. National Institute of Standards and Technology. 2010. Accessed September 2016. http://www.nist.gov/el/economics/BEESSoftware.cfm.

$Acid_z =$ Acidification per dollar of output for industry z

$HHA_z =$ Human health –criteria air pollutants – per dollar of output for industry z

$Eut_z =$ Eutrophication per dollar of output for industry z

$OD_z =$ Ozone depletion per dollar of output for industry z

$Sm_z =$ Smog per dollar of output for industry z

$Eco_z =$ Ecotoxicity per dollar of output for industry z

$HHC_z =$ Human health – carcinogens – per dollar of output for industry z

$HHNC_z =$ Human health – non-carcinogen – per dollar of output for industry z

$PE_z =$ Primary energy consumption per dollar of output for industry z

$LU_z =$ Land use per dollar of output for industry z

$WC_z =$ Water consumption per dollar of output for industry z

$x_{z,Y'} =$ Output for industry z with final demand Y'

Energy: One challenge with examining the impacts of manufacturing by industry is that energy impacts become disaggregated into multiple industries such as mining, transportation, and electricity generation. However, an efficiency improvement in energy use within a factory has immediate implications for the impact associated with energy and its supply chain; therefore, energy should be treated as a single unit rather than disaggregated entities. To address this issue, an estimate of the aggregated impacts of energy is examined by altering the final demand vector Y in Equation 6 to the final demand vector Y'' where the final demand for "*electric power generation, transmission, and distribution"* is equal to 1 and demand for all other commodities in the final demand vector Y'' is set to zero. This allows us to calculate the environmental impacts from each industry to produce a unit of impact from assembly-centric manufacturing:

Equation 8

$$
\begin{aligned}
Env_{z,Y''} = {} & \frac{x_{z,Y''} * GWP_z}{\sum_{i=1}^{n} x_{i,Y'} * GWP_i} * 0.30 + \frac{x_{z,Y''} * Acid_z}{\sum_{i=1}^{n} x_{i,Y'} * Acid_i} * 0.03 + \frac{x_{z,Y''} * HHA_z}{\sum_{i=1}^{n} x_{i,Y'} * HHA_i} * 0.09 \\
& + \frac{x_{z,Y''} * Eut_z}{\sum_{i=1}^{n} x_{i,Y'} * Eut_i} * 0.06 + \frac{x_{z,Y''} * OD_z}{\sum_{i=1}^{n} x_{i,Y'} * OD_i} * 0.02 + \frac{x_{z,Y''} * Sm_z}{\sum_{i=1}^{n} x_{i,Y'} * Sm_i} * 0.04 \\
& + \frac{x_{z,Y''} * Eco_z}{\sum_{i=1}^{n} x_{i,Y'} * Eco_i} * 0.07 + \frac{x_{z,Y''} * HHC_z}{\sum_{i=1}^{n} x_{i,Y'} * HHC_i} * 0.08 + \frac{x_{z,Y''} * HHNC_z}{\sum_{i=1}^{n} x_{i,Y'} * HHNC_i} * 0.05 \\
& + \frac{x_{z,Y''} * PE_z}{\sum_{i=1}^{n} x_{i,Y'} * PE_i} * 0.10 + \frac{x_{z,Y''} * LU_z}{\sum_{i=1}^{n} x_{i,Y'} * LU_i} * 0.06 + \frac{x_{z,Y''} * WC_z}{\sum_{i=1}^{n} x_{i,Y'} * WC_i} * 0.08
\end{aligned}
$$

From Equation 8, the indirect impact of electricity (i.e., the impact from other industries such as mining and transportation associated with electricity production) per percentage point of direct impact can be estimated:

Equation 9

$$IIPP_E = \frac{\left[\sum_{i=1}^{n} Env_{z,Y''}\right] - Env_{E,Y''} - Env_{Nat,Y''}}{Env_{E,Y''}}$$

Where

$IIPP_E =$ Indirect Impact per percentage point of direct impact from "*electric power generation, transmission, and distribution"*

$Env_{E,Y''} =$ Environmental impact from the "*electric power generation, transmission, and distribution"* for final demand Y''

$Env_{Nat,Y''} =$ Environmental impact from the "*natural gas distribution*" for final demand Y''

A similar calculation can be made for natural gas where final demand for Y'' is set to 1 for "*natural gas distribution*" and zero for all other commodities:

Equation 10

$$IIPP_{Nat} = \frac{\left[\sum_{i=1}^{n} Env_{z,Y''}\right] - Env_{E,Y''} - Env_{Nat,Y''}}{Env_{Nat,Y''}}$$

Where

$IIPP_{Nat} =$ Indirect Impact per percentage point of direct impact from natural gas

Equation 9 and Equation 10 calculate and parse out the indirect impacts of the energy consumed from the production of assembly-centric manufacturing while incorporating the weights previously discussed.

An additional issue with energy is that it is associated with completely different types of processes and purposes. Some energy is used for heating and cooling of buildings while other energy is used for operating machinery. Grouping these together masks the source of energy consumption. The BEA Input-Output data provides estimates of energy use; however, it does not provide the detail in how the energy is used, which would allow for a more targeted approach to addressing energy efficiency improvements. In order to better understand energy use, the Manufacturing Energy Consumption Survey (MECS) was used to separate the BEA energy data into use categories to show both the quantity of energy consumption as well as the purpose for which the consumption occurs. 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 coal mining, electricity generation, and natural gas distribution by proportions calculated from the Energy Information Administration (EIA). The MECS data and BEA data both have varying levels of NAICS code aggregation. The MECS data can be aggregated up when it is more detailed than the BEA data. When the BEA data is more detailed it is assumed that the proportions remain the same for the detailed NAICS codes. This issue illustrates the need for advanced coordination between data collection entities.

2.3. Value Added

The total requirements matrix $W(I - BW)^{-1}$ from Equation 6, which shows the total output required to meet a given level of final demand, is multiplied by final demand in the input-output data to estimate the total output. The output required to produce a particular level of final demand can be calculated by altering final demand to Y'. For this analysis, Y' equals final demand for those NAICS codes representing assembly-centric products and zero for those that do not, making this an examination of assembly-centric products and their supply chains.

Value added is calculated by assuming the proportion of output needed to produce a commodity is the same proportion of value added, which is consistent with methods proposed by Miller (2009). The proportions calculated using the input-output analysis are then multiplied by the value added and scaled to 2014 dollars using the estimate of gross output for that year:

Equation 11

$$VA_{z,Y',2014} = \frac{x_{z,Y',2007}}{x_{z,2007}} * VA_{z,2007} * \left(\frac{x_{z,2014}}{x_{z,2007}}\right)$$

Where

$VA_{z,Y',2014}$ = Value added from industry z with final demand Y' in 2014

$x_{z,2007}$ = Total output for industry z in 2007

$x_{z,2014}$ = Total output for industry z in 2014

$x_{z,Y',2007}$ = Output for industry z with final demand Y' in 2007

$VA_{z,2007}$ = Total value added from industry z in 2007

Imports are calculated in a similar fashion, where the proportion of total output used from a particular industry is the same for imports.

Energy Analysis: Similar to the environmental analysis, value added was broken into energy use categories including: *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*.

2.4. Labor

In order to examine labor activity, Bureau of Labor Statistics employment data from the Occupational Employment Statistics is matched with the BEA IO NAICS categories. For this analysis, the Bureau of Labor Statistics employment data has been mapped to the detail level found in the 2007 Benchmark Input-Output data. In instances where the NAICS codes for the occupation data did not match that of the input-output data, the values were estimated. 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 at 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 by the total weeks per year. These hours are then multiplied by wages per hour and adjusted to match the BEA estimates of compensation assuming the BEA proportions of labor are the same as that calculated using BLS data. When examining a specific product commodity such as automotive manufacturing, the input-output calculations are used to estimate the output from each industry required to produce the given product. The proportion of the total output needed from each industry is multiplied by the occupational employment for each industry to estimate the amount of labor, which is consistent with methods proposed in Miller (2009). The result is a matrix of the amount of labor needed, categorized by NAICS by occupation, to produce the relevant commodity.

Equation 12

$$C_{z,s,Y'} = \frac{x_{z,Y'}}{x_z} * C_{z,s,} * \left(\frac{E_{z,s} * LH_s * W_{z,s}}{\sum_{i=1}^{n} E_{z,i} * LH_s * W_{z,i}}\right) * \left(\frac{x_{z,2014}}{x_{z,2007}}\right)$$

Where

$C_{z,s,Y'}$ = Compensation for occupation s in industry z with final demand Y'

$C_{z,s,}$ = Total compensation for occupation s in industry z

x_z = Total output for industry z

$x_{z,Y'}$ = Output for industry z with final demand Y'

$E_{z,s}$ = Employment for industry z and occupation s

LH_s = Labor hours per employee for occupation s

$W_{z,s}$ = Hourly wages per employee for industry z and occupation s

2.5. Gross Value of Depreciable Assets

Depreciable assets are measured in a similar fashion to labor. The proportion of output estimated from the input-output calculations is multiplied by the total depreciable assets for that industry, resulting in an estimate of depreciable assets utilized for the production of the commodity being examined. An estimate for buildings and machinery/equipment is made by utilizing RS Means data. The total square footage of manufacturing space from the Manufacturing Energy Consumption survey is multiplied by the average construction cost per square foot from RS Means. This is assumed to be the buildings share of depreciable assets with the remaining amount assumed to be machinery/equipment:

Equation 13

$$DB_{z,Y'} = \frac{x_{z,Y',2007}}{x_{z,T,2007}} * (SF_z * RM)$$

Equation 14

$$DM_{z,Y'} = \left[\frac{x_{z,Y',2007}}{x_{z,T,2007}} * DA_z\right] - DB_{z,Y'}$$

Where

$DB_{z,Y',MB}$ = Depreciable building assets from industry z associated with final demand Y' in 2014

$DM_{z,Y'}$ = Depreciable machinery assets from industry z associated with final demand Y' in 2014

$x_{z,T,2007}$ = Total output for industry z in 2007

$x_{z,Y',2007}$ = Output for industry z with final demand Y' in 2007

SF_z = Estimated square feet of manufacturing floor space for industry z

RM = RS Means estimated construction cost per square foot of manufacturing floor space

DA_z = Gross value of depreciable assets (end of year) from the annual survey of manufactures

A similar calculation is made for the purchase of new and used capital assets, where the proportion of output estimated from the input-output calculations is multiplied by the value of new and used capital assets purchased.

Equation 15

$$CE_{z,Y',MB} = \frac{x_{z,Y',2007}}{x_{z,T,2007}} * CE_{MB}$$

Where

$CE_{z,Y',MB}$ = Capital expenditures by industry z with final demand Y' on MB, where MB is either machinery or buildings

$x_{z,T,2007}$ = Total output for industry z in 2007

$x_{z,Y',2007}$ = Output for industry z with final demand Y' in 2007

$CE_{z,MB}$ = Total capital expenditures by industry z on MB, where MB is either machinery or buildings

3. Data

There are a number of datasets needed to examine costs, environmental impacts, time flow, and capital. These datasets include the Annual Survey of Manufactures from the US Census Bureau, the Economic Census from the US Census Bureau, the Bureau of Economic Analysis (BEA) Benchmark Input-Output data, environmentally extended input-output data, Occupational Employment Statistics from the Bureau of Labor Statistics, Energy Consumption Survey from the Energy Information Administration, and RS Means cost data. These datasets are described below.

Input-Output Data: Every five years the BEA computes benchmark input-output tables, which tends to have over 350 industries.[29] The data is provided in the form of make and use tables, with their corresponding matrices replacing the Leontief method. [30] In the US, industries are categorized by NAICS codes. 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 in this context an “establishment” is a single physical

[29] Bureau of Economic Analysis. Input-Output Accounts Data. November 2014. Accessed September 2016. http://www.bea.gov/industry/io_annual.htm.

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

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; however, establishments often have multiple activities. 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 standard make-use tables.

Manufacturing 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). 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. The Economic Census, used for years ending in 2 or 7, is a survey of all employer establishments in the US that has been taken as an integrated program at 5-year intervals since 1967. Both the ASM and the Economic Census use NAICS classifications. 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.

Data on Plant Hours: 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. In addition to providing capacity utilization, it also provides data on the average plant hours per week in operation for an industry.[31]

Environmental Data: For environmental data, this paper applies a suite of environmentally extended Input-Output databases for Life Cycle Assessments (LCA) developed under contract for NIST by Dr. Sangwon Suh of the Bren School of Environmental Science and Management at the University of California, Santa Barbara.[32] This data has been utilized in a number of environmental efforts, including NIST's Building for Environmental and Economic Sustainability (BEES)[33] and Building Industry Reporting and Design for Sustainability (BIRDS)[34] software and related publications. This data utilizes the 12 TRACI 2 impact categories: global warming potential, primary energy consumption, human health – criteria air pollutants, human health – carcinogens, water consumption, ecological toxicity[35], eutrophication[36], land use, human health – non-carcinogens, smog formation, acidification, and ozone depletion. The units of measurement are provided in Table 1. This environmental data is organized by 2002 BEA codes for the Benchmark Input-Output tables, and matched and adjusted to the 2007 BEA Input-Output tables. The environmental data was adjusted from being in impact units per 2002 dollars to impact units per 2007 dollars using the consumer price index from the Bureau of Labor Statistics.

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[31] US Census Bureau. Survey of Plant Capacity Utilization: How the Data are Collected. Accessed September 2016. http://www.census.gov/manufacturing/capacity/how_the_data_are_collected/.

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

[33] National Institute of Standards and Technology. Building for Environmental and Economic Sustainability. Accessed September 2016. http://www.nist.gov/el/economics/BEESSoftware.cfm.

[34] National Institute of Standards and Technology. Building Industry Reporting and Design for Sustainability. Accessed September 2016. https://birdscom.nist.gov/.

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

[36] 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

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 NAICS. The OES categorizations includes over 800 occupations and over 450 industries; however, archived data covers fewer industries (Bureau of Labor Statistics). 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. The data is provided by NAICS codes and by the Standard Occupational Classification System. Two industry categories of labor data were not available to be broken out: construction and agriculture. However, the costs of this labor are included in the capital purchases and industry purchases categories.

Energy Data: The Energy Information Administration collects energy data through the Manufacturing Energy Consumption Survey (Energy Information Administration). It is conducted on a quadrennial basis and samples approximately 15 500 establishments drawn from a nationally representative sample frame that includes 97 % to 98 % of the manufacturing payroll. Energy data is categorized by the NAICS codes and end use. For this analysis it is used to break the input-output data into more specific categories. This survey also provides the square footage of manufacturing floor space by NAICS code. This value is used to estimate the construction value of the buildings that house manufactured goods.

Depreciable Assets Data: In years ending in 2 or 7 the Economic Census is conducted, which is a survey of all employer establishments in the US where the response is required by law. It has been taken as an integrated program at 5-year intervals since 1967. Both the ASM and the Economic Census use NAICS classification; however, prior to NAICS the Standard Industrial Classification system was used. The Economic Census sent out nearly 4 million forms to businesses representing all US locations and industries. Four items from this data is used in this paper: gross depreciable assets, retirements, capital expenditures on buildings, and capital expenditures on machinery.

Building Data: RS Means provides data on construction costs for a range of building types and components. The cost per square foot of factory construction was used to estimate the value of constructed buildings housing manufacturing activity (RS Means 2005).

4. Results and Discussion

This paper develops a methodology using input-output data and analysis combined with other industry data to examine whether resources are disproportionally consumed in the production of a particular finished commodity, in this case automobiles, and if so, what activities account for this higher consumption. This case study provides a proof of concept in examining national level production for advancing efficiency in other manufacturing industries. The approach considers five measures of resource consumption: the amount of value added from each industry, the total cost of labor by occupation, the environmental impact from each industry, the value of associated gross depreciable assets, and the time it takes for a material to move through an industry (note that this flow time measure is only applicable to industries that handle materials). Flow time and the gross value of depreciable assets relate to the use of capital such as machinery and buildings. These two measures are only available for supply chain entities that are within the manufacturing industry; therefore, industries such as transportation and mining were examined using value added, labor hours, and environmental impact. Since this paper focuses on the distribution of resource consumption, the results are presented in terms of the percent of the total consumption of a particular resource and also in terms of percentile where the largest categories of consumption are among the highest percentile.

As seen in Figure 2, the results show that the consumption of resources is consistent with Pareto's principle where 20 % of the cause represents greater than 80 % of the resource consumption. That is, a subset of supply chain entities represents a disproportional amount of the resource consumption. The results show that 20 % of supply chain entities account for 89 %, 89 %, and 91 % of value added, labor hours, and environmental impacts from automobile manufacturing, respectively. Improving the efficiency in these areas of the supply chain would lead to disproportional reductions in the resources needed for production. The distribution of value added, labor hours by industry, labor hours by occupation, and environmental impacts are such that they have a Gini coefficient of 0.87, 0.86, 0.86, and 0.87, respectively. The Gini coefficient is a measure of statistical dispersion where 0 represents equal distribution (i.e., each cost category represents the same proportion of total cost) and 1 represents total unequal distribution.

The results by industry for value added, labor hours, and environmental impact are shown in Table 2, Table 3, and Table 4, respectively. Each are categorized by industry NAICS code, which are categories of establishments, as illustrated in Figure 1. Table 2 shows that the final assembly of the automobile (NAICS 336111) is approximately 17 % of the total cost measured in value added, which means that nearly 83 % of the costs occur throughout establishments in the supply chain. "Wholesale trade" is the next highest (7.7 %) with sales people from this industry being a significant contributor (not shown). The 3rd, 4th, and 5th ranked supply chain entities are automobile parts industries (engine parts (336310), transmission and power train parts (336350), and other automotive parts (336390)). The "management of companies and enterprises" (e.g., company headquarters) is ranked 6th, which emphasizes the cost of operating large automobile manufacturing companies. These top 6 industries account for 45.6 % of the value added.

Labor hours in Table 3, Figure 3, and Table 6 are categorized by industry NAICS code; thus, it is the total labor occurring at categories of establishments. Labor is also categorized by occupation, as seen in Table 5. In terms of labor hours by industry, the final assembly (NAICS336111) (18.0 %), "wholesale trade" (9.5 %), and the "management of companies and enterprises" (5.6 %) activities are the largest consumers of labor. Moreover, these categories of establishments account for a larger proportion of labor hours than other categories of establishments in the supply chain. In terms of labor hours by occupation, "team assemblers" (14.5 %), "laborers and freight, stock, and material movers" (2.7 %), and "machinists" (2.5 %) are the largest contributors while five additional occupations account for 2.0 % to 2.5 % each and 16 account for 1.0 % to 2.0 %. These are the sum of labor hours throughout the supply chain for each occupation. If we recall the supply chain illustration in Figure 1, our approach is similar to summing the total labor hours in each industry for a particular occupation required to produce the finished commodity. Using either approach to categorize labor hours, labor is more broadly distributed across the supply chain than the value added.

Environmental impacts are categorized by industry NAICS codes. In terms of environmental impacts (Table 4), "automobile manufacturing" (22.0 %), "iron and steel mills and ferroalloy manufacturing" (6.3 %), "electricity and natural gas" (4.9 %), and "glass and glass product manufacturing (4.8 %) are the four largest contributors. Moreover, these categories of establishments account for a larger proportion of environmental impacts than other categories in the supply chain for automobile manufacturing.

Many of the same industries account for large fractions of value added, labor, and environmental impacts. Figure 3 and Table 6 identify those items that are above the 80th percentile for labor hours, environmental impact, and value added (i.e., those items that appear in Table 2, Table 3, and Table 4). There are 6 items that appear above the 95th percentile for all categories and 16 total items above the 90th percentile. "Electricity and natural gas" for all purposes (NAICS 2121, 2211, 2212) along with "glass and glass product manufacturing" (NAICS 327200), "iron and steel mills and ferroalloy manufacturing" (NAICS 331110), "automobile manufacturing" (NAICS 336111), "wholesale trade" (NAICS 420000), and "truck transportation" (NAICS 484000) were above the 95th percentile for all three measures. These establishment categories (i.e., NAICS codes), consume a disproportional amount of resources compared to other establishments in the automobile supply chain.

In addition to "Iron and steel mills and ferroalloy manufacturing" (NAICS 331110) being above the 95th percentile, a number of other metal and steel categories appear above the 90th percentile in all three measures, including "steel product manufacturing from purchased steel" (NAICS 331200), "ferrous metal foundries" (NAICS 331510), and "nonferrous metal foundries" (NAICS 331520). The high ranking of these metal and steel oriented categories emphasizes that the efficient use of steel can have a high impact on multiple resource measures relating to multiple stakeholders. There may also be opportunities for efficiency improvement in the use of metal and steel, as it is estimated that more than a quarter of steel is scrapped in the production process.[37] A number of entities have made this deduction and are focusing their research efforts on these efficiency improvements. For example, the National Institute of Standards and Technology has an automotive lightweighting group that examines these issues. The US Geological Survey estimates that 15 % of steel is scrapped when steel is cut, drawn, extruded, or machined.[38]

"Truck transportation" (NAICS 484000) appeared above the 95th percentile and "rail transportation" (NAICS 482000) appeared above the 90th percentile for all three measures. Additionally, "laborers and freight, stock, and material movers, hand" (SOC 537062) was the second largest labor occupation category in Table 5 and "heavy and tractor-trailer truck drivers" (SOC 533032) was 7th. The appearance of these items emphasizes that efficiency improvements in transportation throughout the supply chain can have a high impact on multiple resource categories relating to multiple stakeholders. There might be opportunities for efficiency improvement in this area, as approximately 20 % of truck miles are driven with no product being transported,[39]. Reducing these empty miles would decrease labor, capital expenditures, and traffic. Several methods are being considered across the global economy to reduce these excess miles. In Germany, a new auction platform aims to improve truck space utilization.[40] Other efforts to co-load or ride-share have also received some attention. Innovative solutions like these might reduce the resources consumed in the transport of goods.

As previously mentioned, "wholesale trade" (NAICS 420000) appears above the 95th percentile for all three categories. Wholesalers sell or arrange the purchase/sale of goods to other businesses from a warehouse or office. Customers are, generally, reached through in-person communication, which might explain why "sales representatives" (SOC 414012) and "sales representatives, wholesale/manufacturing, technical/scientific products" (SOC 414011) are ranked 5th and 45th in labor hours in Table 5.[41] Advancing the dissemination of information on intermediate products might reduce the sales burden needed for distributing intermediate parts and components to producers. In addition to sales activity, wholesalers function as a warehouse to store inventory. Additional warehousing costs are categorized as "warehousing and storage" (NAICS 493000), which is above the 80th percentile in cost (Table 2), and labor hours (Table 3). Warehouses are needed to buffer for unpredictable fluctuations in demand. Improved forecasting in demand might lessen the need for inventory/warehousing and in turn reduce wholesale trade costs.

Figure 4 and Table 7 show manufacturing industries above the 70th percentile for environmental impact, flow time, labor hours, value added, and depreciable assets for automobile manufacturing. Figure 4 and Table 7 select supply chain entities only from establishments categorized as manufacturing entities that

[37] Allwood, Julian M and Jonathan M Cullen. Sustainable Materials with Both Eyes Open. UIT Cambridge Ltd. 2012. Accessed January 2017. http://www.withbotheyesopen.com/index.html.
[38] Fenton, Michael D. "Iron and Steel Recycling in the United States in 1998." US Geological Survey. 3. Accessed January 2017. https://pubs.usgs.gov/of/2001/of01-224/.
[39] Bureau of Transportation Statistics, US Department of Transportation. Freight Facts and Figures 2015. Table 3-11 page 41. Accessed January 2017. https://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/FFF_complete.pdf.
[40] Science Daily. "Ride-Sharing for Road Freight." Accessed January 2017. https://www.sciencedaily.com/releases/2011/04/110406132022.htm.
[41] US Census Bureau. North American Industry Classification System. Accessed January 2017. http://www.census.gov/eos/www/naics/.

handle intermediate components. These are the establishments that would, typically, be considered by a manufacturer to be a supplier. Other establishments categorized as non-manufacturing (e.g., management of companies and enterprises) are, therefore, not included. The 70th percentile is used, as there are very few industries where all five measures are above the 80th percentile. "Iron and steel mills and ferroalloy manufacturing" (NAICS 331110) is the only manufacturing supply chain entity that is above the 90th percentile for all five factors shown in Table 7. Only two additional items are at or above the 80th percentile: "other electronic component manufacturing" (NAICS 33441A) and "copper rolling, drawing, extruding and alloying" (NAICS 331420). These are the high resource consumption entities among those that would, typically, be considered a supplier.

5. Summary

This paper examines whether the resources used in the production of a specific commodity are consistent with the Pareto principle, and advances the identification of those supply chain entities that account for a disproportionally high level of resource consumption by examining automobile manufacturing as a case study. A multi-factor approach is used where the time, cost, labor, environmental impact, and depreciable assets are examined to facilitate the identification of economy-wide opportunities for efficiency improvement in manufacturing. Those production activities that consume high levels of resources across the different measures provide a strong opportunity for efficiency improvements affecting multiple stakeholders. The results suggest that the cost distribution is consistent with the Pareto principle where 20 % of the industries in the supply chain represent greater than 80 % of the total resource consumption. The data show that 20 % of supply chain entities account for 89 %, 89 %, and 91 % of value added, labor hours, and environmental impacts from automobile manufacturing, respectively. Six industries were above the 95th percentile in value added, environmental impact, and labor hours for automobile manufacturing while an additional 10 are above the 90th percentile. "Electricity and natural gas" for all purposes (NAICS 2121, 2211, 2212) along with "glass and glass product manufacturing" (NAICS 327200), "iron and steel mills and ferroalloy manufacturing" (NAICS 331110), "automobile manufacturing" (NAICS 336111), "wholesale trade" (NAICS 420000), and "truck transportation" (NAICS 484000) were above the 95th percentile for all three measures. Transportation, steel, sales, and warehousing appear in multiple ways (i.e., labor categories, industry categories, and different resource types) and there might be opportunities for efficiency improvement in these areas. For instance, for 20 % of the miles driven for truck transportation the truck is empty and more than a quarter of steel ends up as scrap, resulting in even more transportation.

For those supply chain entities that handle intermediate parts and components (i.e., the entities that would, traditionally, be considered suppliers), the environmental impact, time, labor hours, and depreciable assets were examined. One item is above the 90th percentile in all five categories, "Iron and steel mills and ferroalloy manufacturing" (NAICS 331110). This category also appeared in Figure 3, which is consistent with steel having a disproportional impact on multiple resource types. An additional two items are above the 80th percentile: "other electronic component manufacturing" (NAICS 33441A) and "copper rolling, drawing, extruding and alloying" (NAICS 331420). The areas identified in this paper as being above the 80th percentile in the consumption of multiple resource types provide strong opportunities for efficiency improvements that impact multiple stakeholders. Reducing resource consumption in these select areas will have a disproportional impact on total resource consumption, including costs and natural resources consistent with Pareto's Principle.

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Figure 1: Supply Chain Illustration

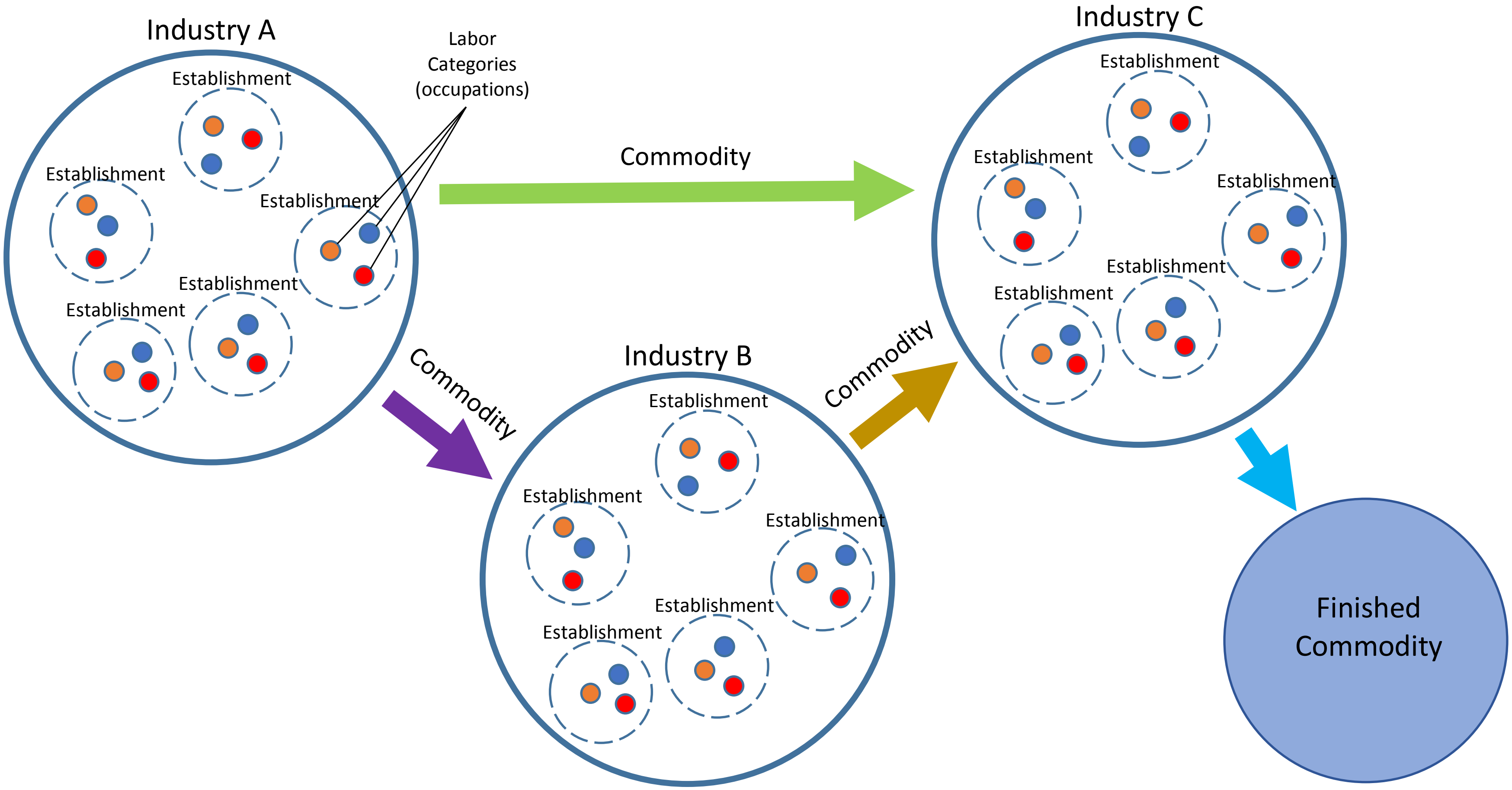


Table 1: Environmental Impact Categories and Weights for Assessing Impact

Items to be measured	**Units**	**Weights**
Global Warming Potential	kg CO_2 eq	0.30
Acidification	H^+ moles eq	0.03
Human Health- Criteria Air Pollutants	kg PM_{10} eq	0.09
Eutrophication	kg N eq	0.06
Ozone Depletion	kg CFC-11 eq	0.02
Smog	kg O_3 eq	0.04
Ecotoxicity	CTUe	0.07
Human Health - Carcinogens	CTUHcan	0.08
Human Health – Non- Carcinogens	CTUHnoncan	0.05
Primary Energy Consumption	thousand BTU	0.10
Land Use	acre	0.06
Water Consumption	kg	0.08

Figure 2: Cumulative Percent of Value Added/Labor/Environmental Impact by Percentile

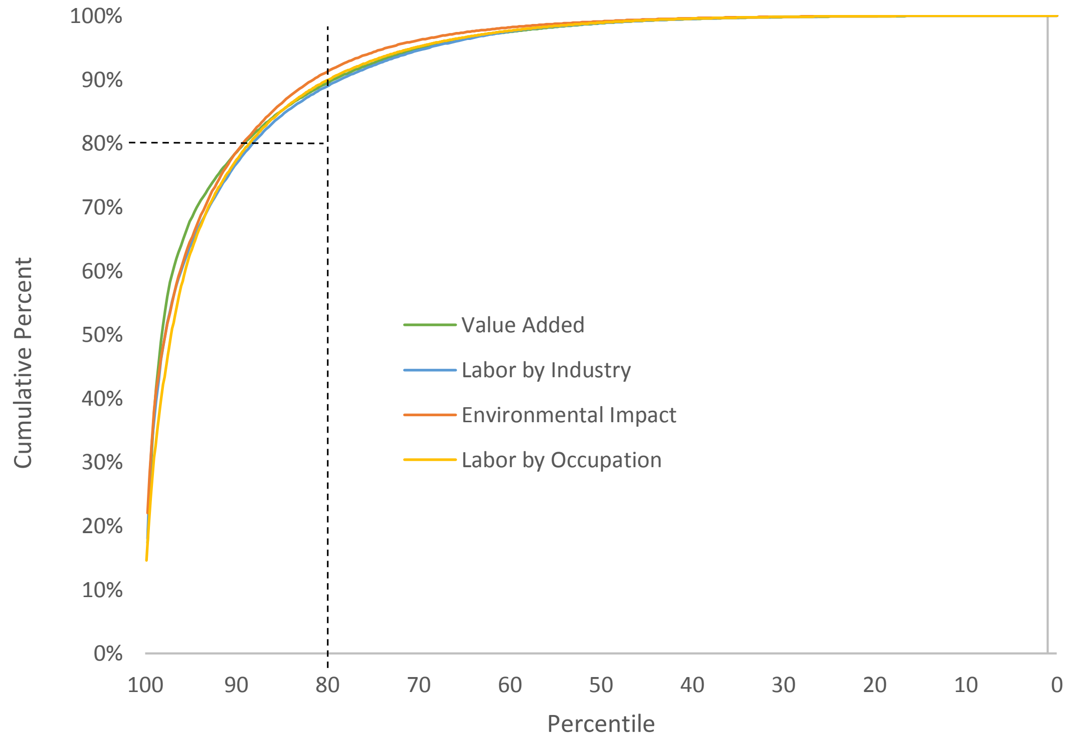


Table 2: Automobile Manufacturing Costs (Measured in Value Added), Top 20 %

Code	NAICS Description	% of Total
336111	Automobile manufacturing	17.32%
420000	Wholesale trade	7.71%
336310	Motor vehicle gasoline engine and engine parts	6.81%
336390	Other motor vehicle parts manufacturing	5.56%
336350	Motor vehicle transmission and power train parts	4.17%
550000	Management of companies and enterprises	4.02%
211000	Oil and gas extraction	3.26%
331110	Iron and steel mills and ferroalloy manufacturing	2.59%
3363A0	Motor vehicle steering/suspension/brake systems	2.31%
336360	Motor vehicle seating and interior trim manufacturing	2.22%
336370	Motor vehicle metal stamping	2.20%
333618	Other engine equipment manufacturing	1.33%
336320	Motor vehicle electrical and electronic equipment	1.21%
212/221	Electricity and Natural Gas	1.14%
334300	Audio and video equipment manufacturing	1.06%
316000	Leather and allied product manufacturing	1.06%
331419	Primary smelting and refining of nonferrous metal	1.01%
327200	Glass and glass product manufacturing	0.94%
332720	Turned product and screw, nut, and bolt manufacturing	0.90%
484000	Truck transportation	0.88%
326190	Other plastics product manufacturing	0.81%
324110	Petroleum refineries	0.74%
334413	Semiconductor and related device manufacturing	0.63%
332710	Machine shops	0.61%
33441A	Other electronic component manufacturing	0.59%
541100	Legal services	0.55%
52A000	Monetary authorities and depository credit	0.55%
326210	Tire manufacturing	0.55%
331510	Ferrous metal foundries	0.53%
331520	Nonferrous metal foundries	0.53%
531ORE	Other real estate	0.52%
541610	Management consulting services	0.49%
33291A	Valve and fittings other than plumbing	0.47%
482000	Rail transportation	0.45%
561300	Employment services	0.45%
331200	Steel product manufacturing from purchased steel	0.43%
331411	Primary smelting and refining of copper	0.42%
325211	Plastics material and resin manufacturing	0.42%
524100	Insurance carriers	0.41%
333612	Speed changer/industrial high-speed drive/gears	0.41%

Code	NAICS Description	% of Total
533000	Lessors of nonfinancial intangible assets	0.40%
33131A	Alumina refining and primary aluminum production	0.40%
541200	Accounting/tax preparation/bookkeeping/payroll services	0.39%
336112	Light truck and utility vehicle manufacturing	0.39%
33399B	Fluid power process machinery	0.39%
325190	Other basic organic chemical manufacturing	0.34%
33411A	Computer terminals and other computer peripheral equipment	0.34%
541800	Advertising, public relations, and related services	0.34%
212100	Coal mining	0.33%
332500	Hardware manufacturing	0.33%
561700	Services to buildings and dwellings	0.33%
541300	Architectural, engineering, and related services	0.32%
332991	Ball and roller bearing manufacturing	0.32%
331490	Nonferrous metal rolling/drawing/extruding/alloying	0.31%
332800	Coating, engraving, heat treating and allied activities	0.30%
230301	Nonresidential maintenance and repair	0.29%
2122A0	Iron, gold, silver, and other metal ore mining	0.29%
33299B	Other fabricated metal manufacturing	0.28%
325110	Petrochemical manufacturing	0.28%
326110	Plastics packaging materials and unlaminated film/sheets	0.27%
334514	Totalizing fluid meter and counting device manufacturing	0.26%
517110	Wired telecommunications carriers	0.26%
336211	Motor vehicle body manufacturing	0.25%
5419A0	Marketing/professional/scientific/technical services	0.25%
333613	Mechanical power transmission equipment manufacturing	0.24%
332310	Plate work and fabricated structural product manufacturing	0.23%
33211B	Crown and closure manufacturing and metal stamping	0.22%
493000	Warehousing and storage	0.22%
331420	Copper rolling, drawing, extruding and alloying	0.22%
322210	Paperboard container manufacturing	0.22%
326290	Other rubber product manufacturing	0.21%
333415	Air conditioning, refrigeration, and warm air heating equipment	0.21%
523A00	Securities and commodity contracts intermediation/brokerage	0.20%
522A00	Nondepository credit intermediation and related activities	0.20%
326220	Rubber and plastics hoses and belting manufacturing	0.20%
325510	Paint and coating manufacturing	0.20%
339990	All other miscellaneous manufacturing	0.19%
335920	Communication and energy wire and cable manufacturing	0.19%
221100	Electric power generation, transmission, and distribution	0.19%
541512	Computer systems design services	0.19%

Table 3: Automobile Manufacturing Labor Hours, Top 20 %

Code	NAICS Description	% of Total
336111	Automobile manufacturing	17.97%
420000	Wholesale trade	9.49%
550000	Management of companies and enterprises	5.57%
336350	Motor vehicle transmission/power train parts manufacturing	3.29%
336310	Motor vehicle gasoline engine/engine parts manufacturing	3.29%
336390	Other motor vehicle parts manufacturing	3.25%
336370	Motor vehicle metal stamping	3.17%
332710	Machine shops	2.01%
484000	Truck transportation	1.94%
336360	Motor vehicle seating and interior trim manufacturing	1.92%
561300	Employment services	1.72%
3363A0	Motor vehicle steering/suspension/brake manufacturing	1.56%
326190	Other plastics product manufacturing	1.32%
561700	Services to buildings and dwellings	1.18%
327200	Glass and glass product manufacturing	1.16%
331510	Ferrous metal foundries	1.10%
331520	Nonferrous metal foundries	1.07%
331110	Iron and steel mills and ferroalloy manufacturing	0.93%
332720	Turned product and screw, nut, and bolt manufacturing	0.91%
336320	Motor vehicle electrical/electronic equipment	0.87%
336211	Motor vehicle body manufacturing	0.81%
332800	Coating, engraving, heat treating and allied activities	0.78%
541610	Management consulting services	0.77%
333618	Other engine equipment manufacturing	0.74%
561400	Business support services	0.72%
52A000	Monetary authorities and depository credit intermediation	0.71%
493000	Warehousing and storage	0.67%
722110	Full-service restaurants	0.67%
212/221	Electricity and Natural Gas	0.65%
541300	Architectural, engineering, and related services	0.64%
334300	Audio and video equipment manufacturing	0.61%
316000	Leather and allied product manufacturing	0.60%
541200	Accounting, tax preparation, bookkeeping, and payroll services	0.59%
326210	Tire manufacturing	0.58%
541100	Legal services	0.58%
331200	Steel product manufacturing from purchased steel	0.54%
332310	Plate work and fabricated structural product manufacturing	0.53%
334413	Semiconductor and related device manufacturing	0.52%
482000	Rail transportation	0.52%
722211	Limited-service restaurants	0.51%

Code	NAICS Description	% of Total
33211B	Crown and closure manufacturing and metal stamping	0.49%
561600	Investigation and security services	0.46%
332991	Ball and roller bearing manufacturing	0.45%
33441A	Other electronic component manufacturing	0.43%
322210	Paperboard container manufacturing	0.42%
4A0000	Other retail	0.42%
531ORE	Other real estate	0.41%
522A00	Nondepository credit intermediation and related activities	0.41%
48A000	Scenic/sightseeing transportation and support activities	0.41%
492000	Couriers and messengers	0.40%
33291A	Valve and fittings other than plumbing	0.38%
33399B	Fluid power process machinery	0.37%
332320	Ornamental and architectural metal products manufacturing	0.36%
441000	Motor vehicle and parts dealers	0.35%
33211A	All other forging, stamping, and sintering	0.35%
339990	All other miscellaneous manufacturing	0.33%
541800	Advertising, public relations, and related services	0.33%
541512	Computer systems design services	0.33%
326110	Plastics packaging materials/unlaminated film/sheet manufacturing	0.31%
5419A0	Marketing/professional/scientific/technical services	0.30%
524200	Insurance agencies, brokerages, and related activities	0.29%
524100	Insurance carriers	0.28%
211000	Oil and gas extraction	0.26%
326290	Other rubber product manufacturing	0.25%
721000	Accommodation	0.25%
562000	Waste management and remediation services	0.24%
33299B	Other fabricated metal manufacturing	0.24%
333415	Air conditioning/refrigeration/warm air heating equipment	0.24%
332600	Spring and wire product manufacturing	0.24%
323110	Printing	0.24%
523A00	Securities and commodity contracts intermediation and brokerage	0.23%
54151A	Other computer related services, including facilities management	0.22%
326220	Rubber and plastics hoses and belting manufacturing	0.21%
561900	Other support services	0.21%
212100	Coal mining	0.21%
325211	Plastics material and resin manufacturing	0.21%
481000	Air transportation	0.20%
811300	Commercial/industrial machinery/equipment repair/maintenance	0.20%
314900	Other textile product mills	0.19%
325510	Paint and coating manufacturing	0.19%

Note: Electricity/natural gas can appear twice. One as the total (NAICS 212/221) and the uses of energy (e.g., NAICS 221100-B)

Table 4: Environmental Impact of Automobile Manufacturing, Top 20 %

Code	NAICS Description	% of Total
336111	Automobile manufacturing	22.00%
331110	Iron and steel mills and ferroalloy manufacturing	6.25%
212/221	Electricity and Natural Gas	4.86%
327200	Glass and glass product manufacturing	4.79%
111900	Other crop farming	3.33%
316000	Leather and allied product manufacturing	2.56%
2122A0	Iron, gold, silver, and other metal ore mining	2.40%
324110	Petroleum refineries	1.87%
484000	Truck transportation	1.83%
325180	Other basic inorganic chemical manufacturing	1.78%
113000	Forestry and logging	1.71%
325190	Other basic organic chemical manufacturing	1.59%
211000	Oil and gas extraction	1.51%
325211	Plastics material and resin manufacturing	1.39%
321200	Veneer/plywood/engineered wood product	1.26%
221100	Electric power generation/transmission/distribution	1.23%
313200	Fabric mills	1.11%
3252A0	Synthetic rubber/artificial and synthetic fibers and filaments	1.07%
420000	Wholesale trade	1.02%
325110	Petrochemical manufacturing	0.91%
482000	Rail transportation	0.89%
331520	Nonferrous metal foundries	0.88%
326190	Other plastics product manufacturing	0.83%
212100	Coal mining	0.83%
221100-D	Machine Drive	0.82%
33131A	Alumina refining and primary aluminum production	0.79%
331200	Steel product manufacturing from purchased steel	0.78%
33441A	Other electronic component manufacturing	0.76%
331510	Ferrous metal foundries	0.75%
336112	Light truck and utility vehicle manufacturing	0.68%
313100	Fiber, yarn, and thread mills	0.66%
336390	Other motor vehicle parts manufacturing	0.63%
333618	Other engine equipment manufacturing	0.61%
339990	All other miscellaneous manufacturing	0.61%
326210	Tire manufacturing	0.59%
331490	Nonferrous metal rolling/drawing/extruding/alloying	0.58%
322210	Paperboard container manufacturing	0.56%
1121A0	Beef/cattle ranching/farming/feedlots	0.54%
550000	Management of companies and enterprises	0.53%
1111B0	Grain farming	0.49%

Code	NAICS Description	% of Total
321100	Sawmills and wood preservation	0.46%
322130	Paperboard mills	0.46%
332720	Turned product and screw, nut, and bolt manufacturing	0.45%
31161A	Animal (except poultry) slaughtering, rendering, and processing	0.42%
336350	Motor vehicle transmission and power train parts manufacturing	0.42%
324190	Other petroleum and coal products manufacturing	0.42%
336310	Motor vehicle gasoline engine and engine parts manufacturing	0.41%
331419	Primary smelting/refining of nonferrous metal	0.40%
313300	Textile and fabric finishing and fabric coating mills	0.40%
3219A0	All other wood product manufacturing	0.40%
562000	Waste management and remediation services	0.39%
326110	Plastics packaging material/unlaminated film/sheet manufacturing	0.39%
331411	Primary smelting and refining of copper	0.38%
332800	Coating, engraving, heat treating and allied activities	0.37%
336370	Motor vehicle metal stamping	0.35%
33131B	Aluminum product manufacturing from purchased aluminum	0.33%
212230	Copper, nickel, lead, and zinc mining	0.33%
221100-B	Process Heating	0.33%
331420	Copper rolling, drawing, extruding and alloying	0.32%
332114	Custom roll forming	0.32%
325510	Paint and coating manufacturing	0.32%
332710	Machine shops	0.31%
33211A	All other forging, stamping, and sintering	0.31%
33299B	Other fabricated metal manufacturing	0.30%
314110	Carpet and rug mills	0.29%
221200-B	Process Heating	0.27%
336211	Motor vehicle body manufacturing	0.27%
221100-G	Facility HVAC (g)	0.25%
327100	Clay product and refractory manufacturing	0.25%
481000	Air transportation	0.24%
33211B	Crown and closure manufacturing and metal stamping	0.24%
326290	Other rubber product manufacturing	0.23%
332310	Plate work and fabricated structural product manufacturing	0.23%
336360	Motor vehicle seating and interior trim manufacturing	0.23%
1111A0	Oilseed farming	0.23%
322120	Paper mills	0.22%
315000	Apparel manufacturing	0.21%
561700	Services to buildings and dwellings	0.20%
334413	Semiconductor and related device manufacturing	0.20%
314900	Other textile product mills	0.20%

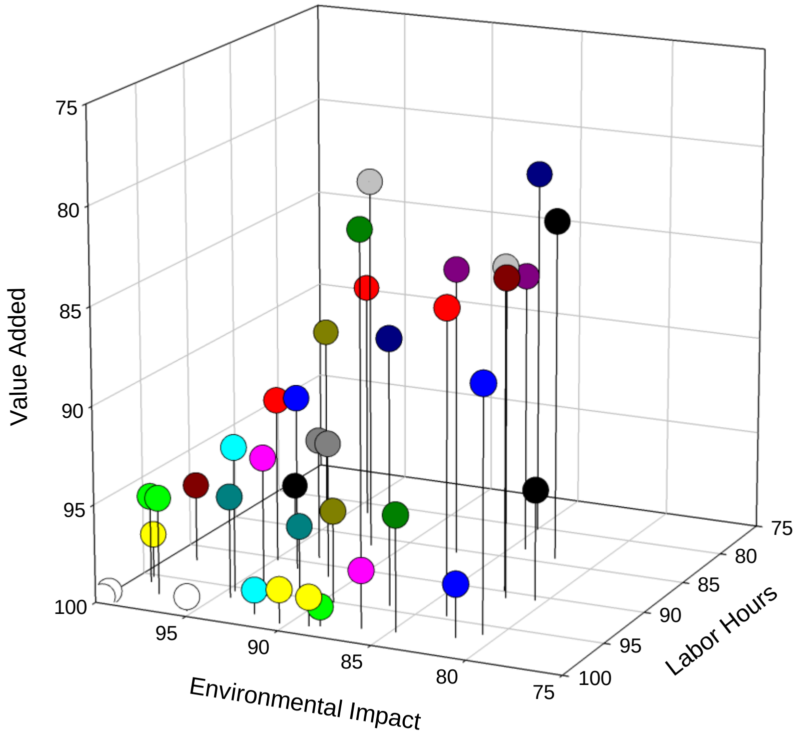
Note: Electricity/natural gas can appear twice. One as the total (NAICS 212/221) and the uses of energy (e.g., NAICS 221100-B)

Table 5: Labor Hours for Automobile Manufacturing by Occupation, Top 20 %

Code	NAICS Description	% of Total
512092	Team Assemblers	14.54%
537062	Laborers and Freight, Stock, and Material Movers, Hand	2.73%
514041	Machinists	2.49%
511011	First-Line Supervisors of Production and Operating Workers	2.43%
414012	Sales Representatives (Wholesale and Manufacturing)	2.32%
512099	Assemblers and Fabricators, All Other	2.06%
533032	Heavy and Tractor-Trailer Truck Drivers	2.04%
519061	Inspectors, Testers, Sorters, Samplers, and Weighers	2.03%
111021	General and Operations Managers	1.78%
434051	Customer Service Representatives	1.65%
439061	Office Clerks, General	1.46%
499071	Maintenance and Repair Workers, General	1.39%
172112	Industrial Engineers	1.38%
499041	Industrial Machinery Mechanics	1.34%
537051	Industrial Truck and Tractor Operators	1.26%
514031	Cutting/Punching/Press Machine Setters/Operators/Tenders, Metal/Plastic	1.26%
435071	Shipping, Receiving, and Traffic Clerks	1.21%
514121	Welders, Cutters, Solderers, and Brazers	1.14%
132011	Accountants and Auditors	1.12%
514011	Computer-Controlled Machine Tool Operators, Metal and Plastic	1.11%
433031	Bookkeeping, Accounting, and Auditing Clerks	1.07%
519198	Helpers--Production Workers	1.07%
514111	Tool and Die Makers	1.04%
519199	Production Workers, All Other	1.00%
436014	Secretaries/Administrative Assistants, Except Legal/Medical/Executive	0.96%
172141	Mechanical Engineers	0.91%
113051	Industrial Production Managers	0.85%
435081	Stock Clerks and Order Fillers	0.84%
514072	Molding/Coremaking/Casting Setters/Operators/Tenders, Metal/Plastic	0.83%
372011	Janitors and Cleaners, Except Maids and Housekeeping Cleaners	0.82%
514081	Multiple Machine Tool Setters, Operators, and Tenders, Metal and Plastic	0.77%
472111	Electricians	0.77%
537064	Packers and Packagers, Hand	0.75%
431011	First-Line Supervisors of Office and Administrative Support Workers	0.71%
533033	Light Truck or Delivery Services Drivers	0.70%
512022	Electrical and Electronic Equipment Assemblers	0.66%
514122	Welding, Soldering, and Brazing Machine Setters, Operators, and Tenders	0.61%
131199	Business Operations Specialists, All Other	0.58%
512031	Engine and Other Machine Assemblers	0.57%
435061	Production, Planning, and Expediting Clerks	0.53%

Code	NAICS Description	% of Total
131023	Purchasing Agents, Except Wholesale, Retail, and Farm Products	0.52%
113031	Financial Managers	0.50%
514033	Grinding/Lapping/Polishing/Buffing Tool Setters/Operators/Tenders, Metal/Plastic	0.49%
491011	First-Line Supervisors of Mechanics, Installers, and Repairers	0.49%
414011	Sales Representatives, Wholesale/Manufacturing, Technical/Scientific Products	0.48%
131161	Market Research Analysts and Marketing Specialists	0.45%
339032	Security Guards	0.45%
131111	Management Analysts	0.45%
412031	Retail Salespersons	0.44%
112022	Sales Managers	0.44%
151121	Computer Systems Analysts	0.43%
131071	Human Resources Specialists	0.43%
151132	Software Developers, Applications	0.42%
436011	Executive Secretaries and Executive Administrative Assistants	0.41%
119041	Architectural and Engineering Managers	0.40%
519111	Packaging and Filling Machine Operators and Tenders	0.40%
514021	Extruding and Drawing Machine Setters, Operators, and Tenders, Metal and Plastic	0.39%
413099	Sales Representatives, Services, All Other	0.37%
519121	Coating, Painting, and Spraying Machine Setters, Operators, and Tenders	0.37%
151151	Computer User Support Specialists	0.35%
499043	Maintenance Workers, Machinery	0.35%
373011	Landscaping and Groundskeeping Workers	0.34%
353021	Combined Food Preparation and Serving Workers, Including Fast Food	0.33%
516031	Sewing Machine Operators	0.32%
493031	Bus and Truck Mechanics and Diesel Engine Specialists	0.30%
353031	Waiters and Waitresses	0.30%
173026	Industrial Engineering Technicians	0.29%
519041	Extruding, Forming, Pressing, and Compacting Machine Setters, Operators, and Tenders	0.29%
151133	Software Developers, Systems Software	0.29%
514034	Lathe and Turning Machine Tool Setters, Operators, and Tenders, Metal and Plastic	0.29%
151142	Network and Computer Systems Administrators	0.28%
533031	Driver/Sales Workers	0.28%
519122	Painters, Transportation Equipment	0.27%
113021	Computer and Information Systems Managers	0.27%
131081	Logisticians	0.27%
499044	Millwrights	0.27%
411012	First-Line Supervisors of Non-Retail Sales Workers	0.27%
434171	Receptionists and Information Clerks	0.27%
231011	Lawyers	0.26%
433021	Billing and Posting Clerks	0.25%

Figure 3: Automobile Manufacturing Supply Chain Entities Above the 70th Percentile for Labor Hours, Environmental Impact, and Value Added



Note: Table 6 is the Key to the colors in this figure

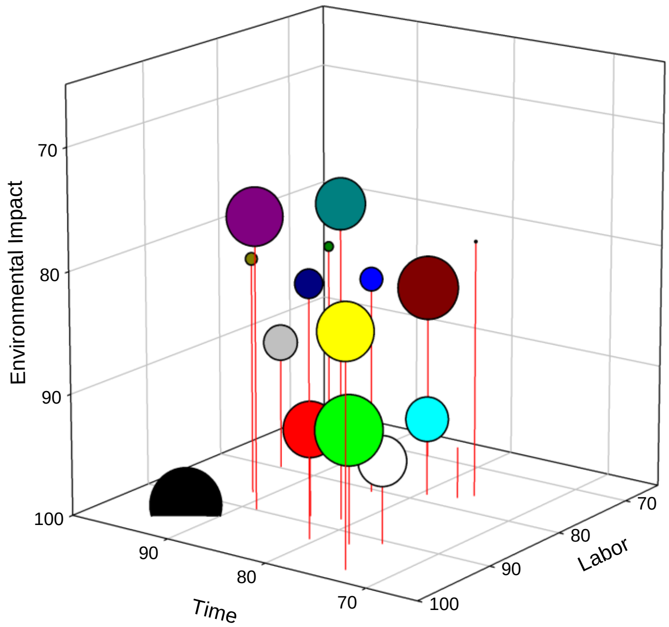
Table 6: Automobile Manufacturing Supply Chain Entities Above the 80th Percentile for Labor Hours, Environmental Impact, and Value Added

	Color	Code	NAICS Description	Percentile		
				Labor	Envir. Impact	Value Added
**		2121, 2211, 2212	Electricity and Natural Gas	100	100	100
**		336111	Automobile manufacturing	100	100	100
**		420000	Wholesale trade	99	95	99
**		331110	Iron and steel mills and ferroalloy manufacturing	95	99	98
**		327200	Glass and glass product manufacturing	96	99	96
**		484000	Truck transportation	98	98	95
*		336390	Other motor vehicle parts manufacturing	98	92	99
*		550000	Management of companies and enterprises	99	90	98
*		316000	Leather and allied product manufacturing	92	99	96
*		326190	Other plastics product manufacturing	97	94	95
*		331520	Nonferrous metal foundries	96	95	93
*		333618	Other engine equipment manufacturing	94	92	97
*		331510	Ferrous metal foundries	96	93	93
*		482000	Rail transportation	90	95	92
*		326210	Tire manufacturing	92	91	93
*		331200	Steel product manufacturing from purchased steel	91	93	91
		336350	Motor vehicle transmission and power train parts manufacturing	99	89	99
		336310	Motor vehicle gasoline engine and engine parts manufacturing	99	88	99
		336370	Motor vehicle metal stamping	98	86	97
		332720	Turned product and screw, nut, and bolt manufacturing	95	89	95
		211000	Oil and gas extraction	84	97	98
		332710	Machine shops	98	85	94
		336360	Motor vehicle seating and interior trim manufacturing	97	82	97
		33441A	Other electronic component manufacturing	89	93	94
		325211	Plastics material and resin manufacturing	81	97	91
		332800	Coating, engraving, heat treating and allied activities	94	87	86
		334413	Semiconductor and related device manufacturing	91	81	94
		561700	Services to buildings and dwellings	96	81	87
		212100	Coal mining	82	94	88
		336211	Motor vehicle body manufacturing	95	83	84
		322210	Paperboard container manufacturing	89	91	83
		339990	All other miscellaneous manufacturing	86	92	81
		326110	Plastics packaging materials/unlaminated film/sheet manufacturing	85	87	85
		332310	Plate work and fabricated structural product manufacturing	91	82	84
		33211B	Crown and closure manufacturing and metal stamping	90	83	83
		33299B	Other fabricated metal manufacturing	83	84	86
		326290	Other rubber product manufacturing	84	82	83
		325510	Paint and coating manufacturing	80	85	81

** All above 95th percentile

* All above 90th percentile

Figure 4: Automobile Manufacturing Supply Chain Entities Above the 70th Percentile for Time, Labor, Environmental Impact, Value Added, and Depreciable Assets (Only Manufacturing Supply-Chain Entities)



Note: The size of the bubbles represent the percentile of value added (80th percentile to the 100th). Table 7 is the key to the colors in this figure.

Table 7: Automobile Manufacturing Supply Chain Entities Above the 70th Percentile for Time, Labor, Environmental Impact, Value Added, and Depreciable Assets (Only Manufacturing Supply-Chain Entities)

			Percentile				
Color	BEA NAICS	Description	Labor Hours	WIP Time	Environmental Impact	Value Added	Depreciable Assets
	331110	Iron and steel mills and ferroalloy manufacturing	95	92	99	98	98
	333618	Other engine equipment manufacturing	92	77	91	96	93
	334413	Semiconductor and related device manufacturing	90	89	76	92	95
	33441A	Other electronic component manufacturing	89	84	93	92	84
	331200	Steel product manufacturing from purchased steel	91	75	93	89	92
	332710	Machine shops	97	74	81	92	93
	331490	Nonferrous metal (except copper and aluminum) rolling, drawing, extruding and alloying	80	94	89	85	86
	331419	Primary smelting and refining of nonferrous metal (except copper and aluminum)	70	85	86	95	87
	33211A	All other forging, stamping, and sintering	86	92	81	77	86
	33291A	Valve and fittings other than plumbing	88	81	74	90	84
	336211	Motor vehicle body manufacturing	93	81	79	82	81
	33131A	Alumina refining and primary aluminum production	78	79	94	88	78
	331420	Copper rolling, drawing, extruding and alloying	81	84	82	81	81
	33131B	Aluminum product manufacturing from purchased aluminum	73	93	83	76	82
	313200	Fabric mills	78	77	96	73	77
	327100	Clay product and refractory manufacturing	76	76	79	73	76