Integrated Circuitry's Integration In Automotive Manufacturing and the Impact on Employment

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Jack Hebert

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Advisor

Rider W. Foley, Department of Engineering and Society

Introduction

Every year, the Virginia Motorsports Club builds an electric formula car (as seen in Figure 1) for Formula SAE competitions, where they then race against other motorsports clubs from other universities.

Figure 1. Virginia Motorsports 2024 Formula Car

One main limitation put in place by FSAE is that a new car must be built every season (which corresponds to the school year), which allows for the best systems of the previous vehicle to be fixed up and re-added while the worst systems get replaced entirely. For this season, the new lead of the electrical team had his eyes set on the most glaring flaw of the previous car: the data acquisition harness. This rat's nest was a jumbled bundle of wires that snaked its way from the central data collection computer, through the frame, into each of the four wheels of the car. Each wheel had numerous sensors, gathering everything from wheel speed to brake temperature. Given that all of these sensors output their data in analog signals, it was decided that each sensor simply be wired directly into the central computer. When you factored in the number of sensors per wheel, this resulted in a bundle of roughly 20 wires connected to every wheel. Not only did this result in a harness that was incredibly failure-prone, but it weighed down the car itself as well, which defeats the point of a race car.

Case Context

My Capstone group stepped in to update this antiquated harness. This project focuses on replacing the current analog data acquisition system with an integrated circuit on each wheel that sends all the data on one line via the CAN protocol. CAN, short for Controller Area Network, is a method of compacting several unrelated signals into a single condensed data signal. One way to conceptualize CAN would be, when you have several letters to send to someone, choosing to send them all as a single parcel, instead of sending each letter individually, resulting in all the letters arriving together. CAN is the current automotive standard for data transfer, on account of its high data rate, reliability, and flexibility in connecting a variety of electronic control units to a single data line. We used CAN FD, which is the newest iteration of CAN, with it having 8 times more data storage per message than its predecessor CAN 2.0. This CAN signal is sent to the central data acquisition computer in a single pair of twisted wires, down from the original 20+ of the old analog harness. This knowledge on integrated circuits can be effectively used for my STS topic on how the circuits need to be viewed as an actor with its own desires, which falls in line with Actor Network Theory.

STS Framework

While adding integrated circuits and other digital devices to vehicles has clear monetary and function value, it comes at the cost of the employment of everyday workers in the United States. The US automotive industry, which was once booming, has been left a hollow shell of its former self as all of the unskilled labor positions have been exported to overseas countries with more lax labor laws, leaving all of the remaining jobs in the industry requiring higher education in circuit design and programming. Utilizing Bruno Latour’s framework of Actor Network

Theory found in the 1992 paper "Where Are the Missing Masses? The Sociology of a Few Mundane Artifacts", one can begin to piece together how these different groups impact and are impacted by the technology.

Latour (1992) states that Actor Network Theory (ANT) is used to "[resolve] the technological determinism/social constructivism dichotomy in technology studies", which take opposing positions on whether technology influences society or society influences technology, respectively. ANT posits instead that, while "sociotechnical systems are developed through negotiations between people, institutions, and organizations", it misses out on the fact "that [the] artifacts are part of these negotiations as well." That means that one must consider the interaction between technology and society a two-way street, with each being molded to the other's benefit.

Looking at what the actors do and what they need to be done by the other actors gives an insight into how the industry has been shaped and where it will continue from here. First, there are the automotive companies, which desire to create quality vehicles that can be sold for the most profit. To do this, they increase features to improve quality and price tags, and decrease costs. This impacts all the other major actors, with the consumers getting more features at a higher price tag, the workers being replaced with cheaper or more efficient options, and the artifact of focus (integrated circuitry), gaining demand due to its capability of more robust feature sets at lower costs. Consumers have similar desires as the corporations, with the notable exception of increasing price tags. This results in a further push for corporations to cut costs while increasing features, which then propagates to the other actors. This furthers the need for better integrated circuits and cheaper workers. Ultimately, it is the workers that suffer as a result of these needs. The main manufacturing workforce is exported to cheaper overseas sweatshops, leaving behind only the integrated circuit design. Ultimately, integrated circuitry forms the perfect example for ANT, in that both the societal actors impact how technology is molded and utilized, and the technological actor in turn has its own desires that affect the human actors. While they are designed to create more robust features to satisfy the companies and the consumers, they also impart their needs for a more skilled workforce.

On the other hand, there are concepts like prescriptions, in which the nonhuman actors impose back on the human actors (sometimes rigidly, in the case of discrimination). The integrated circuit has its own needs and desires. It prescribes its mechanical and technical needs on those who build and design them, and it prescribes its monetary needs on those who purchase them. These delicate pieces of technology require the utmost care and delicacy, which discriminates upon the laborers the need to be incredibly careful with the circuitry, or risk losing their jobs.

Research Topic and Methods

Introducing integrated circuitry has widespread effects throughout automotive manufacturing. The people that have the least agency in influencing these results are undoubtedly the laborers, who are at the mercy of their employers. This leads to the main question: How has the continued adoption of integrated circuits in the automotive industry impacted employment within it?

To further research this question, I have combined two different avenues. First, I have reviewed labor statistics in the automotive industry at large in order to discern the overall trends, starting from 1939. To do this, the US Bureau of Labor Statistics (BLS) database was utilized, showing changes in employment over time. Next, another timeline was created, this time for the adoption of integrated circuitry and CAN, which is pulled from the *Handbook of Automotive Power Electronics and Motor Drives* and the CAN in Automation group's technical documentation. This second timeline will be generated from two sources. The *Handbook of Automotive Power Electronics and Motor Drives* covers every single possible section of electronics found in cars. The main focus is chapter 6, titled "Automotive Power Semiconductor Devices", which is most in line with my research topic. The CAN in Automation group's technical documentation chronicles the various versions of CAN and how it has progressed over time. These timelines were then combined, showing how they interacted with each other over time.

In order to have the data cover as wide of a range as possible, several BLS datasets were cross referenced, given that older data was more general. The three sets being used are "all manufacturing employees", "motor vehicle metal stamping employment", and "motor vehicle and parts manufacturing employment", which started in 1939, 1972, and 1990 respectively. Given that both data sets with smaller scopes are subsets of the larger "all manufacturing employees" statistics, certain analyses can be done to allow for extrapolations based on the larger dataset. In order to prove that any extrapolations will be valid, the data needed to be standardized. I chose to do this via z-score, a statistical analysis technique that measures how many standard deviations a given value is off of the mean of the dataset (Nevil, 2024). Converting to z-score normalizes the data, allowing for it to be compared to datasets of different sizes. This is calculated by subtracting the mean of the data set from a specific value, and dividing it by the mean of the data set.

Results

Overall, three major technological advancements coincided with notable shifts in the employment trends in the automotive manufacturing industry. First the initial incorporation of ICs in 1970 marked the beginning of an oscillating plateau after 30 straight years of growth. Then 1987's introduction of CAN greatly reduced that oscillation, until the wider adoption of it in 1990 actually matched an increase in employment, before a sharp decline a few years later.

I used the motor vehicle and parts manufacturing employment statistics as a baseline, and compared it to the metal stamping data, in order to confirm that the trends within the metal stamping data were indicative of the automotive manufacturing industry's employment trends. This proved successful, showing that the standardized data sets matched up incredibly closely, as shown in Figure 2. The average difference in z-score between the two sets was a mere 0.19 standard deviations (Figure 3). This allows for the metal stamping statistics to be added to the baseline data set, giving another point of comparison with the manufacturing data set.

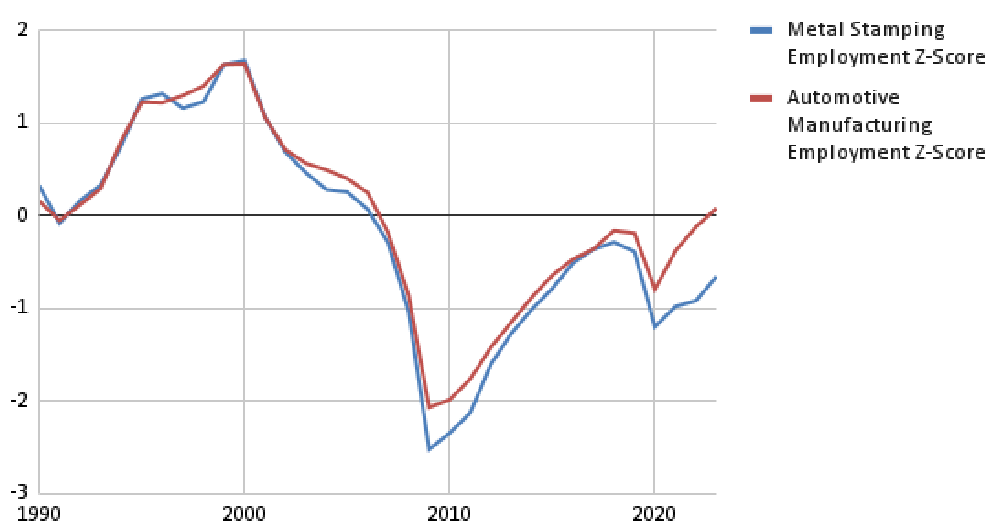

Figure 2. Z-Score of Metal Stamping and Automotive Manufacturing Employment over time.

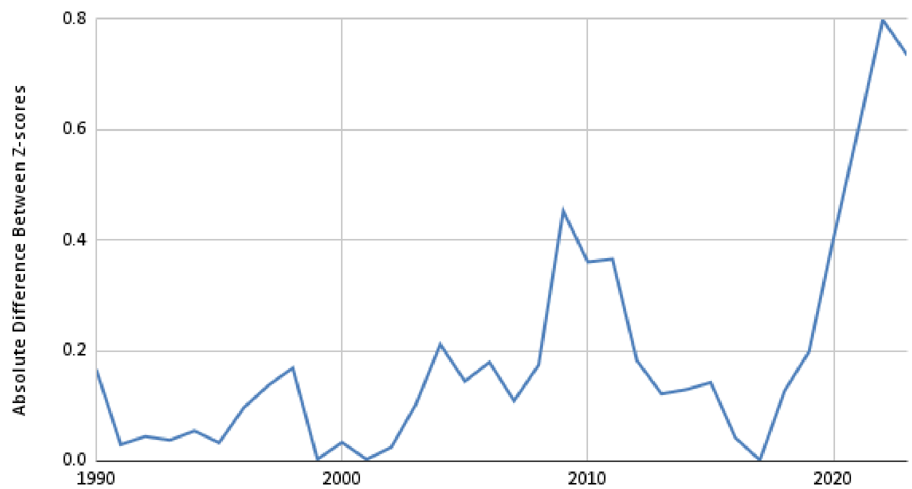

Figure 3. Absolute Value of difference between Metal Stamping and Automotive Manufacturing Employment z-scores.

After standardizing the manufacturing data set, it is evident that the trends that are true for the more granular data sets are also true for this set (Figure 4). However, the trends are not as volatile, which makes sense. Once you increase the scale, the stats are going to be more stable. To get a sense of this scale, in 2023, the manufacturing industry had a total employment of just under 13 million, while the automotive manufacturing sector had barely over 1 million, meaning that it constitutes around 8% of the total manufacturing employment in the United States. Despite this fact, the average difference between the manufacturing employment statistics and the smaller sets still falls within 1 standard distribution. For the motor vehicle manufacturing data, it falls at 0.63, and metal stamping is 0.65 difference in the standard deviations (Figure 5). These standardized data sets provide sufficient evidence that the manufacturing industry's employment statistics can be analyzed to determine the trends of the automotive manufacturing industry housed within it.

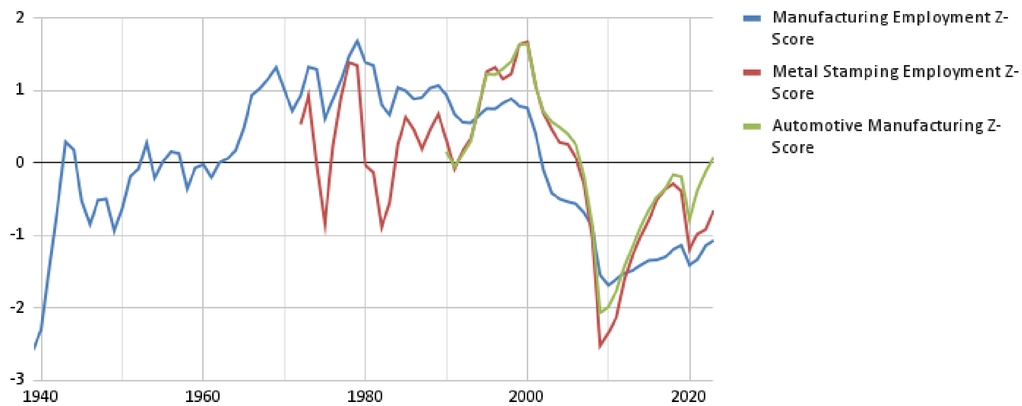

Figure 4. Z-Score of all 3 standardized employment datasets.

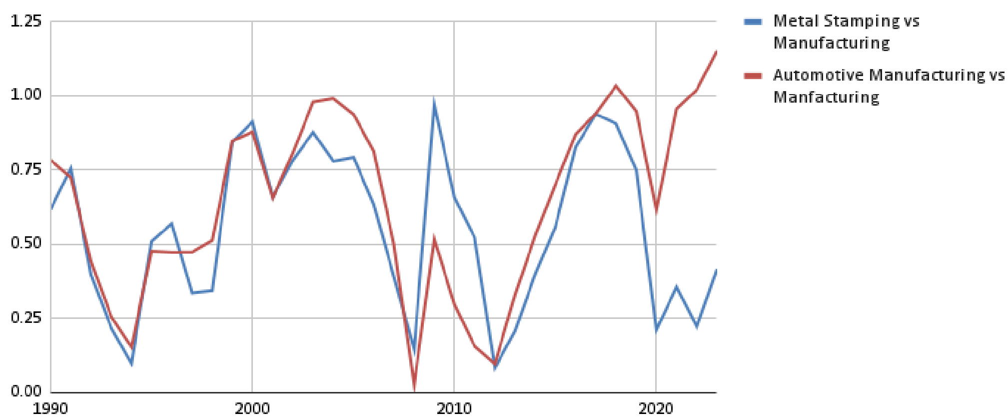

Figure 5. Absolute Value of the difference between Manufacturing employment and either Metal Stamping or Automotive Manufacturing employment.

Integrated circuitry was quite possibly the largest change to the automotive manufacturing industry since its inception. While the basic solid state semiconductor devices first began to hit the market in the 40s, it wasn't until 1970 that they finally made their way into motor vehicles. In this year, the medium-scale integration ICs became readily available. These chips were approximately 100 times more complex than the basic semiconductors (Ribbens, 2017). This resulted in an increase in functionality which, alongside a relatively low cost, resulted in steady adoption of the technology over the upcoming years (Emadi, 2005). The perfect example of this adoption is the advent and widespread usage of the Controller Area

Network (CAN) serial bus system. CAN is a method of compacting several unrelated signals into a single condensed data signal (Corrigan, 2016). One way to conceptualize it would be, when you have several letters to send to someone, choosing to send them all as a single parcel, instead of sending each letter individually, resulting in all the letters arriving together. CAN was first created in 1986, with the first ICs dedicated to it being released the following year (CAN in Automation). It saw quick adoption, mainly in Europe, by companies like Mercedes and BMW in 1991 and 1995 respectively. In the early 90s, a protocol derived from CAN called DeviceNet was created in the US, where it then became the leading databus system. CAN has continued to grow since then, with the release of the CAN 2.0 protocol in 1993 and CAN FD in 2011, which both offered marked improvements in reliability and throughput over their predecessors (Smith, 2024). This timeline of events is compiled below in Figure 6.

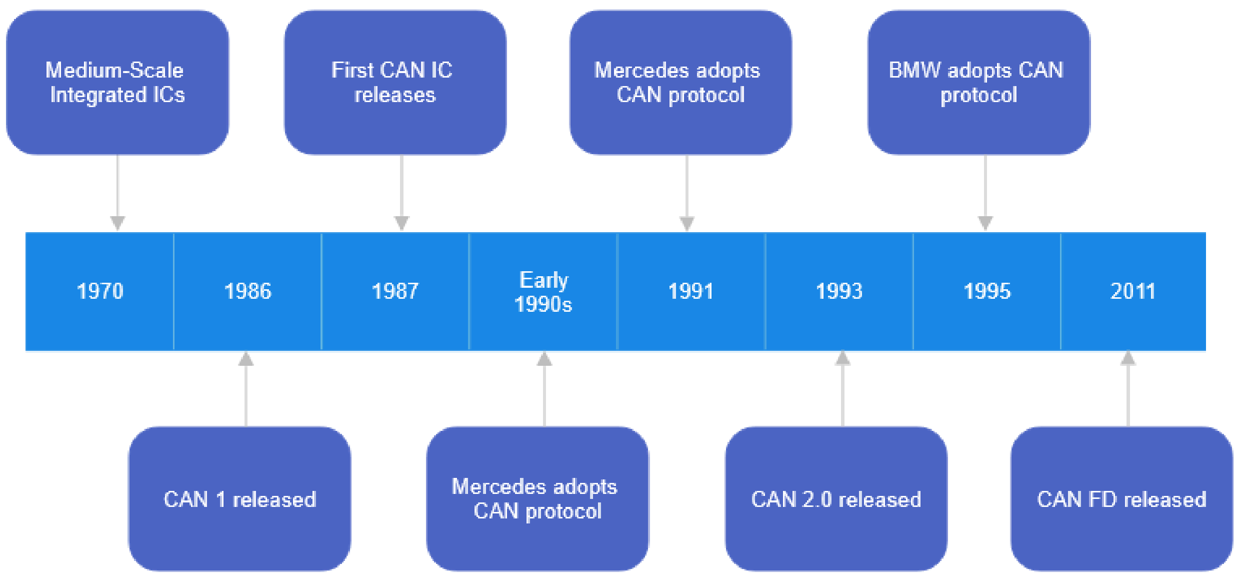

Figure 6. Timeline of ICs and CAN in Automotive Manufacturing.

Marking three major points on the employment graphs, being the initial adoption of ICs in the automotive industry in 1970, the birth of CAN in 1987, and the wider adoption of CAN in the early 90s, it shows that they line up with points of decline (Figure 7).

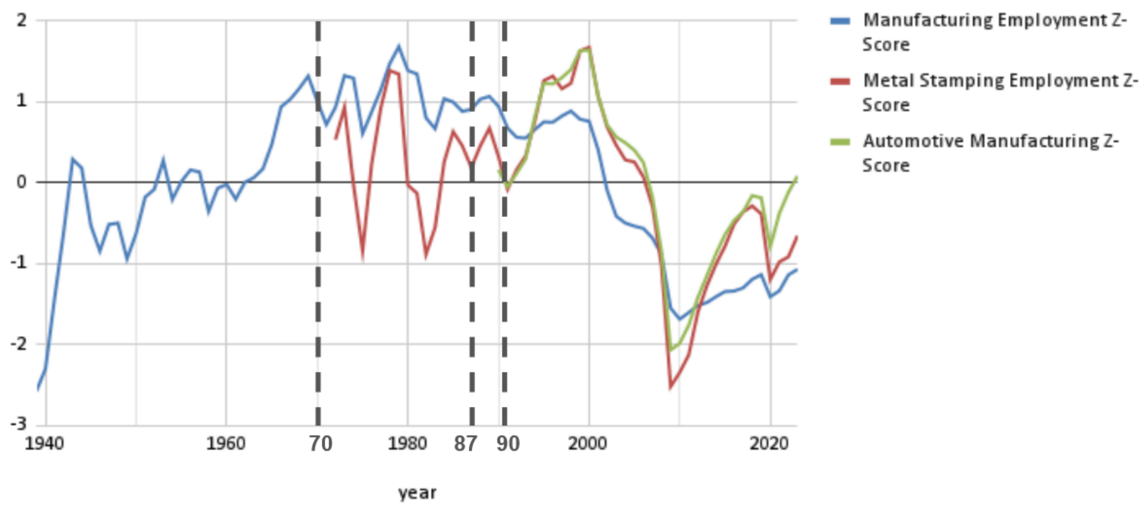

Figure 7. Z-Score chart with important years marked.

1970 is the first year in nearly a decade that has a decline in employment. Before this point, improving the technology scaled with employment due to it all being fully analog. Therefore, if the car companies wanted to make more complex systems in order to appease the desires of the consumers, they had to hire more workers. Once ICs were introduced and digital circuitry began to be the primary method of technological innovations, the correlation with employment began to fall off, leading to companies deprioritizing employment. The slope of the statistics then flatten out for the next decade or two, despite the year to year oscillations. Over this time frame, the integrated circuit became more and more commonplace in motor vehicles. Lining up with the advent of CAN in 1987, that volatility started to decrease, until the early 90s. Following the use of this new technology, employment actually began to increase. However, that trend did not last, and the gradual decline of employment in the automotive industry began, continually growing until it reached a low point in 2009. This was the lowest number of people employed in the industry since 1940. The fact that these major adoption time frames all coincide with or predate points of halted growth or active shrinkage of job opportunities in the industry is an indicator that integrated circuit's usage in automotive manufacturing has harmed the worker's building the vehicles.

Through the lens of Latour's Actor Network Theory (1992), one can begin to piece together the broader forces at play that lead to these trends. There are 4 main actors, being the car company, the consumers who purchase the car, the laborers who manufacture the vehicles, and the vehicle's themselves, being the only non-human actor. Each of these groups have their own desires, which are often at conflict with the other actor groups. They impose these wants onto the others, and those with more economic power are able to do so more effectively. First, there are the automotive companies, which desire to create quality vehicles that can be sold for the most profit. To do this, they increase features to improve quality and price tags, and decrease costs. This impacts all the other major actors, with the consumers getting more features at a higher price tag, the workers being replaced with cheaper or more efficient options, and the artifact of focus (integrated circuitry), gaining demand due to its capability of more robust feature sets at lower costs. Consumers have similar desires as the corporations, with the notable exception of increasing price tags. This results in a further push for corporations to cut costs while increasing features, which then propagates to the other actors. This furthers the need for better integrated circuits and cheaper workers.

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Discussion

Ultimately, it is the workers that suffer as a result of these needs and prescriptions. The main manufacturing workforce is exported to cheaper overseas sweatshops, leaving behind only the integrated circuit design. Integrated circuitry forms the perfect example for ANT, in that both the societal actors impact how technology is molded and utilized, and the technological actor in turn has its own desires that affect the human actors. The companies want to have the greatest profit margins possible, and therefore look to the consumer's desires for better technology within their vehicles. Therefore, they turned to integrated circuitry to make more advanced technology for cheaper. While ICs are designed to create more robust features to satisfy the companies and the consumers, they also impart their needs for a more skilled workforce. All of these different actors have their own needs, and only the laborer lacks the power in the dynamic to impart their own desires of employment and fair compensation.

Limitations and Caveats

The greatest limitation within this analysis lies within the employment statistics. The fact that there was no data specifically on the automotive manufacturing industry's employment until 1990 made a conclusion more challenging to draw. While standardizing the dataset and comparing it with older, more general datasets did work, having some more in depth data would've been preferable. Due to this limitation, I cannot say that my conclusions are absolutely guaranteed. While I do feel confident that they are valid, it is not outside of the realm of possibilities that other factors lead to these trends.

Future Improvements and Next Steps

One such way of furthering this research would be to cross reference it with data about the decline of the Rust Belt. The Rust Belt was the epicenter of the American auto industry, and it began its decline around a decade or so earlier than what the extrapolated data would indicate. Looking at the loss in employment in the Rust Belt as it declined could give a more holistic insight into the decline in jobs that started in the late 20th century. In the same vein, the influx of job opportunities in the Sun Belt could be factored in, in order to more concretely determine the trends of employment in the industry.

Conclusion

The most effective way to leverage the findings of this is by being more aware of the consequences of creating and improving technology. Utilizing ANT can help give one the ability to view the impacts of their creations in a much broader sense. In this situation, the implementation of ICs gives vehicles more advanced functionality, which benefits the consumer and the producer, but the conversion from analog to digital systems actively harms the laborers manufacturing the vehicles themselves. Weighing the pros and cons of your actions, as well as the secondary impacts, is not something that can or should be taken lightly.

This research is indicative of larger trends across all industries. As we continue to integrate technology into more and more of our daily lives, the amount of people that it has an adverse effect on is bound to increase as well. There is no technology that is objectively beneficial for every single person on the planet. The solution is not to somehow believe that you can be different and create something that universally improves people's lives. Instead, one must think through the groups that the technology will impact, just as much as considering how those groups will impact the technology. Workers are often the group that gets the shortest end of the stick, as they have by far the least agency. Therefore, if there is even one group to consider when weighing the impact of your technology, it's the laborers.

Moving forward, automotive manufacturers should focus more aggressively on job security. Cars are getting more and more expensive, and yet the average worker is reaping none of the rewards. These profits should be passed down to the laborers that are actually creating the products. United Auto Workers is one of the most successful unions in the US, regularly bargaining for higher wages and better benefits for those in the automotive manufacturing industry, and any worker that is not in it should absolutely join it.

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Appendix

Year	Manufacturing (thousand)	Manufacturing (Z)	Metal Stamping (thousand)	Metal Stamping (Z)	Auto Manufacturing (thousand)	Auto Manufacturing (Z)
1939	9450.3	-2.572				
1940	10101.6	-2.294				
1941	12127.1	-1.430				

1942	14040.2	-0.614				
1943	16163.3	0.292				
1944	15909.8	0.184				
1945	14253.8	-0.523				
1946	13504.4	-0.842				
1947	14276.7	-0.513				
1948	14316.5	-0.496				
1949	13279.4	-0.938				
1950	14014.1	-0.625				
1951	15070.1	-0.174				
1952	15289.8	-0.081				
1953	16128.7	0.277				
1954	14999.2	-0.205				
1955	15521.3	0.018				
1956	15855.9	0.161				
1957	15797.0	0.136				
1958	14656.3	-0.351				
1959	15325.7	-0.065				
1960	15437.3	-0.018				
1961	15009.8	-0.200				
1962	15497.1	0.008				
1963	15631.9	0.065				
1964	15888.7	0.175				
1965	16618.2	0.486				
1966	17680.8	0.940				

1967	17897.2	1.032				
1968	18210.8	1.166				
1969	18572.3	1.320				
1970	17847.1	1.011				
1971	17171.0	0.722				
1972	17664.1	0.933	103.0	0.534		
1973	18584.16667	1.325	109.4	0.933		
1974	18512.25	1.294	94.1	-0.021		
1975	16912.58333	0.612	81.0	-0.838		
1976	17537.5	0.879	98.2	0.235		
1977	18173.75	1.150	109.2	0.921		
1978	18935.66667	1.475	116.7	1.389		
1979	19427.58333	1.685	116.0	1.345		
1980	18732.41667	1.388	94.0	-0.027		
1981	18634	1.346	92.4	-0.127		
1982	17363.58333	0.804	80.3	-0.882		
1983	17049.16667	0.670	85.6	-0.551		
1984	17920.66667	1.042	98.6	0.259		
1985	17818.5	0.998	104.6	0.634		
1986	17551.91667	0.885	101.8	0.459		
1987	17608.5	0.909	97.5	0.191		
1988	17905.33333	1.035	101.8	0.459		
1989	17984	1.069	105.3	0.677		
1990	17694.8253	0.946	99.7	0.328	1054.2	0.162
1991	17067.88286	0.678	93.2	-0.077	1017.6	-0.047
1992	16800.45984	0.564	97.1	0.166	1047.0	0.121

1993	16776.11011	0.554	99.8	0.334	1077.8	0.296
1994	17023.95582	0.659	106.6	0.758	1168.5	0.814
1995	17244.35174	0.753	114.7	1.264	1241.5	1.230
1996	17236.63889	0.750	115.6	1.320	1240.3	1.223
1997	17417.87216	0.827	113.1	1.164	1253.9	1.301
1998	17560.00937	0.888	114.2	1.233	1271.5	1.401
1999	17322.78046	0.787	120.6	1.632	1312.5	1.635
2000	17265.33032	0.762	121.3	1.675	1313.6	1.641
2001	16440.73327	0.411	111.6	1.070	1212.9	1.067
2002	15258.3929	-0.094	105.5	0.690	1151.2	0.715
2003	14513.13496	-0.412	101.9	0.465	1125.3	0.567
2004	14316.994	-0.496	99.0	0.284	1112.8	0.496
2005	14227.77843	-0.534	98.6	0.259	1096.7	0.404
2006	14160.32948	-0.563	95.6	0.072	1070.0	0.252
2007	13882.65411	-0.681	89.8	-0.289	994.2	-0.180
2008	13405.33413	-0.885	77.9	-1.032	875.5	-0.857
2009	11854.19701	-1.547	54.1	-2.516	664.1	-2.063
2010	11533.14267	-1.684	56.9	-2.342	678.5	-1.981
2011	11727.3986	-1.601	60.4	-2.123	717.7	-1.758
2012	11927.33116	-1.515	68.8	-1.599	777.3	-1.418
2013	12016.20212	-1.477	74.1	-1.269	824.8	-1.147
2014	12182.76491	-1.406	78.3	-1.007	872.1	-0.877
2015	12333.20066	-1.342	81.9	-0.782	913.7	-0.640
2016	12348.08703	-1.336	86.3	-0.508	944.3	-0.465
2017	12439.03113	-1.297	88.7	-0.358	963.4	-0.356
2018	12689.38059	-1.190	89.9	-0.283	998.4	-0.156
2019	12823.22737	-1.133	88.3	-0.383	993.5	-0.184
2020	12181.96458	-1.407	75.3	-1.194	887.5	-0.789
2021	12356.88993	-1.332	78.8	-0.976	960.0	-0.375
2022	12817.46626	-1.136	79.8	-0.913	1005.7	-0.115
2023	12976.07071	-1.068	84.0	-0.651	1040.5	0.084