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Abstract. In 2005 Sanders Consulting published its ground-breaking research, “Why Mass Customization is the Ultimate Lean Manufacturing System.” Using the textile industry as their primary example, Sanders’ research showed that, when framed from the entire product lifecycle—from raw material production to point of purchase, the standard best practice of mass production was actually very inefficient and indeed wasteful in terms of money, time and natural resources. Beginning from this lifecycle framework provided by Sanders, this paper answers the question: What are the environmental impacts of utilizing mass customization compared to the impacts of utilizing mass production?

Keywords. Environmental Impact, Carbon Footprint, Energy Use, Material Use, Mass Customization, Mass Production.

Introduction & Hypothesis

We began the research for this paper with the hypothesis that mass customization (MC) manufacturing and distribution out perform mass production (MP) processes in terms of energy efficiency and material use. Dramatic reductions in inventory, materials, and better utilization of the end-product (an intangible result
of personalization) we believe are the main factors that give mass customized products this efficiency and can yield a lower carbon footprint. This is valuable data for manufacturers and users of MC products as most of the evidence provided to date on more sustainable or ‘green’ products is not empirical and relies heavily on marketing schemes and advertising campaigns.

In order to go about proving (or disproving) this theory we examined the product life-cycle of a men’s dress shirt within both a MC system and a MP system. While there are many levels on which to analyze the embodied energy of a dress shirt, including pre-production processes such as raw material (cotton) extraction and harvesting, yarn spinning and weaving, or even examining the embodied energy in product design processes, this paper will focus its analysis within Sanders’ framework, as provided in their 2005 study, “Why Mass Customization is the Ultimate Lean Manufacturing System,” and examine the production, distribution and customer experience cycles. Specifically, our analysis includes the embodied energy analysis of manufacturing—cutting, sewing, packaging; distribution—warehousing, distributing and retailing; and lastly, the customer purchasing experience.

Research Methodology

For our research we conducted interviews with ten apparel industry experts including fellow researchers, consultants, MC and MP factory managers, and executives currently running MC apparel companies. Most of the interviews were conducted through a series of phone calls, however, a few were held in
person. From these interviews we were able to gather largely qualitative data and some quantitative data of energy use during the manufacturing and distribution cycles.

In addition to industry leader interviews, and as a way to further extend and illustrate a more tangible experience of the product life-cycle analysis, we also documented the purchasing processes required for MC and MP. One of us documented the process of utilizing an online retailer with a custom design configurator to mass customize a shirt; and the other purchased a MP shirt from a retail store in a local shopping district.

We have divided the paper into two sections: the first, Consumer Scenarios, is where we document our consumer experiences of MC and MP; and the second, Analysis, is where we present qualitative and quantitative data on the energy and material use of MC and MP by directly comparing and contrasting the product life-cycle of each. Lastly, we draw conclusions from our scenarios and analysis, and we discuss potential areas of research that could further reveal the energy impacts and potential savings of utilizing mass customization.
Section I: Consumer Scenarios

Mass Customization and Mass Production Consumer Scenarios

Our goal of this exercise was to uncover the total time and energy utilized during the two distinct customer experiences of purchasing similarly-priced MC and MP men's dress shirts. In terms of energy use during these experiences we highlight and compare the amount of time and transportation utilized for each.

For the MC case study we selected Proper Cloth, a men's dress shirt customization platform. Founded by Seph Skerritt, Proper Cloth focuses only on custom men's dress shirts and utilizes a well designed website for first time users. The customer experience can be divided into roughly 6 steps:

1) Create a Shirt - Selection of primary shirt fabric
2) Style - Select type of collar, cuff, and pocket
3) Personalize – Monogram and accent fabrics for cuff and collar
4) Sizing - Body Measurement Methods
5) Summary/Payment
6) Delivery

Figure 1. From home, go online to MC site
Figure 2. Go to Propercloth.com
Step 3

Figure 3. Select fabric.

Step 5 (5-10 min)

Figure 5. Personalize shirt.

Step 7 (15-30 min)

Figure 7. Self measurement.

Step 9 (5 min)

Figure 9. Convert measurements.

Step 4

Figure 4. Select collar, cuff, and pocket.

Step 6 (2-5 min)

Figure 6. Select sizing method

Step 8 (10 min)

Figure 8. Comparative measurement.

Step 10 (10 min)

Figure 10. Summary/Payment
The total time for the MC consumer experience ranged from 1 to 3 hours. This large fluctuation depended on two primary factors: first, the fabric selection available coupled with consumer selectivity; and second, the ease of measurement coupled with the consumer’s skill level in those method(s). In terms of time spent during the consumer selection process, there is the common problem shared by most online design configurators: The platform must simultaneously present enough variety to meet the needs of numerous consumer tastes while providing the consumer with the appropriate level of variety to choose from so as not to overwhelm them.1

In terms of measurement time, ProperCloth.com offers a “Similar Brand Measurement” method that can dramatically reduce time to purchase by allowing consumers to compare the sizing of popular name brand shirts. In addition, Proper Cloth’s body measurement method provides more precise custom tailoring

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1 Barry Schwartz’s book, “Paradox of Choice” describes the decision challenges when presented with too much variety. This area of study has been of central focus of MC researchers in search of the right balance between excessive variety and meaningful choice. Ivengar and Lepper’s study in 2000, “When
capability; however, this requires a greater investment of time. Other barriers to this method might include the lack of tools required of the consumer for measurement such as a fabric tape measure (initially we measured ourselves using a ribbon and a building tape measure) as well as include the necessary skills required of the consumer for self measuring. Overall, the initial consumer time investment for MC is high; however, this will diminish dramatically for repeated orders, once the sizing has been verified.

Mass Production Consumer Scenario
For the MP case study we first picked a local shopping district with the assumption that there would be 3-4 stores we could visit and at one of which, make a purchase. We ended up purchasing a dress shirt from a retailer called, Sean, which sells mass produced lines of men’s fashion apparel. The customer experience can be divided into roughly 5 steps:

1) Travel to Retail Store – Public transit and walking in search of store
2) Selection of Shirt – Choosing between different styles, colors and sizes
3) Fitting – Try on the shirts to verify standard, but good fit
4) Purchase – Payment for selected shirt
5) Travel back Home – Walking and public transit

Choice is Demotivating: Can one Desire Too Much of a Good thing?,” in the Journal of Personality and Social Psychology also points to the need to minimize variety.

Step 1 (35 min)
Figure 13. Travel to local shopping district.

Step 2
Figure 14. First store in shopping mall.

Step 3 (20 min)
Figure 15. Browse store #1 selection of shirts.

Step 4
Figure 16. Unappealing to personal style

Step 5 (25 min)
Figure 17. Travel to another store.

Step 6 (15 min)
Figure 18. Browse store #2 selection.
The total time for the MP consumer experience took about 2.5 hours. Most of that time was spent for travel to and from the various retail locations and the apartment, where compared to the MC case study, zero time is needed for travel. Our main observations here, however, are the distinct sources of energy used by the consumer during that travel (i.e. public transit for us, however, we speculate that average consumers will drive to their shopping centers) as well as the energy used by the retail store to present the selection of shirts and complete the transaction, none of which is needed for MC.
Section II: Analysis of Key Areas

The analysis section is composed of two primary stages within the product life-cycle: manufacturing and distribution. Where we can, for each of these stages we provide detailed energy use analysis and evaluation, and we also provide speculation on potential sources of energy waste and savings we found in both MC and MP.

Manufacturing
The major areas of focus in the manufacturing component of our analysis are the waste and energy required for the following processes:

1. Inventory (raw materials)
2. Cutting, Sewing, and Assembly (fabric utilization)
3. Packaging

Inventory (raw materials)
MP processes in the apparel industry are inherently dependent of large quantities of a limited variety of fabrics, whereas MC processes depend more on having much less quantity, but a larger array of fabric choices. One of the largest European mass customizers of men's dress shirts, Bivolino, utilizes over 55,000 meters of inventory over a 1-2 month period; however, these quantities pale in comparison to the 15,000,000 meters of fabric required by the average MP manufacturer (Byvoet, 2009). In MC, inventory levels can range from as little as 2.5-3 meters (Skerritt, 2009) for highly specialized fabrics to 250 meter rolls
(Byvoet, 2009). Some MC practitioners have reduced the number of fabric choices in order to further maximize this inventory benefit: For example, Proper Cloth allows just 34 types of fabrics as opposed to Bivolino who offers over 200 types of fabrics. As a much smaller manufacturer, Proper Cloth, not only offers less fabric choice, but also fewer choices of collar styles (4 vs. 28) and cuff styles (3 vs. 15) than Bivolino.

The management of inventory directly contributes to the challenge of appropriate variety in MC. Larger MC manufacturers can offer more choice and must accommodate the larger quantities of fabric types, whereas smaller MC manufacturers can essentially bring their inventory to near zero. This points to a shift in inventory management by MC factories upstream to the fabric distributor. Increasing use of MC practices that include one-on-one interactions between MC producers and customers have yielded better real time market data, thus enabling fabric mills to produce materials more efficiently (Possen, 2009).

In cases where manufacturers produce both MP and MC shirts inventory lines are blurred depending on the level of dual-use of fabrics for each line. In the case of Brooks Brothers, the addition of MC production increases the level of in-store inventory, as they have utilized retail locations to promote the MC business.

Cutting, Sewing, and Assembly
MP processes employ multiple ply cutting machines that can cut up to 20-30 layers of fabric at one time (Teel, 2009). The advantage over MC is that total
cutting time is reduced, however, as the number of layers increase cutting accuracy decreases. In MC, however, while single or double ply cutting yields a very accurate cut, it also produces much more paper waste (paper underlayment is required for stabilizing the fabric during cutting). The characteristic of wastage for MP and MC varies greatly. For example, in MC, manufacturers often will wait for orders to accumulate before cutting a particular color in order to maximize usage. In MP, others are very large and require the largest width available, thus creating larger swaths of unused material. The range of fabric utilization advantage of MP over MC is large. Bivolino reported fabric usage of 12% higher for MC (Byvoet, 2009), whereas Brook Brothers was 2-3% (Teel, 2009).

Total time for cutting, sewing, and assembly for MC reported by Bivolino was 10 minutes (cutting) and 60 minutes (sewing and assembly) (Byvoet, 2009). This is roughly 3 times the amount of time for traditional MP processes (Byvoet, 2009). However, an investigation of total production levels as reported by Brooks Brothers at one factory location of 4800 MP shirts/week with 180 operators and 500 MC shirts/week with 20 operators (Teel, 2009), yields nearly identical shirts per worker per week ratios of 26.7 and 25.

Packaging
In general, both MP and MC manufacturers will package each shirt, with MC often personalizing the packaging for their product. Many MP manufacturers will ship shirts in bundles of 20-24 shirts (Teel, 2009), thus greatly reducing the need for outer packaging like cardboard and plastic packaging for shipping. Both MC
and MP producers can greatly reduce environmental impacts by using recycled paper and plastics in packaging. In some special cases, MC reduces the necessary packaging since the retailer does not display the final product, as is the case for Brooks Brothers.

Production Waste
The production of MC products will yield varying levels of waste in fabric and stabilization paper (as described in the manufacturing section) during the production process. The continued optimization of this process through better cutting techniques, utilization of recyclable materials will minimize this impact. These same techniques can be applied to MP processes to achieve similar benefit, however, recycling in the MC process is less of a general problem given the very low number of returns than MP processes.

Distribution
One of the more clear distinctions in the product life-cycle between the MC and the MP of a men’s dress shirt is the process of distribution that each method utilizes after the manufacturing has concluded. At first glance, it seems obvious that MC, which typically allows for direct-to-customer shipping, and without its need for an infrastructure of distribution centers, greatly saves on energy and material use. Our research has confirmed this assumption; however, it turned up evidence that suggests a less obvious and more subtle structure of such savings. In this section we will compare the typical distribution processes of each and
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Customization vs. Mass Production

outline the sources of energy and material savings (and waste) after the product 
has left the factory up until it is in the hands of the customer.

As discussed above, while the energy efficiency gained during the MP 
manufacturing process exceeds that of the current practice of MC, those gains are 
primarily offset by its dependency on large distribution infrastructure such as 
offsite product storage facilities (warehousing) and regional shipping centers. 
Since MC utilizes direct-to-customer shipping, it can function almost entirely 
without this infrastructure providing tremendous energy savings because it does 
not need to heat & cool or supply electricity to such buildings, nor provide fuel 
for and maintain a transportation fleet. Increasing the energy utilized and time 
spent while circulating through the distribution infrastructure, we found that, with 
the exception of only a few manufacturers, most MP manufacturing of men’s 
dress shirts occurred overseas and far from the final distribution point – the 
customer transaction.

The energy savings found in the distribution of MC shirts are not without their 
own offsets and balances, however. For instance, where MP shirts can be 
packaged and shipped in bulk, with one manufacturer reporting a weekly 
shipment of 4,800 - 6,000 units (Teel, 2009), MC shirts are individually packaged 
and sometimes individually shipped. In order to offset the increase of energy 
needed for more packaging materials per product as well as less efficient 
deliveries, we found that the common practice in MC was to batch single orders 
together over a period of time. Typically this means aggregating orders over one
week period whose destinations are similar and shipping those together. However, implementing this strategy returns MC to the problems found in distribution infrastructure.

In addition, similar to the long range found in MP distribution, in talking with apparel industry executives we found that it is common in MC for the manufacturing facility to be at a great distance from the point of customer transaction (Eggers & Luber, 2009). In fact, in some cases this is one of the marketing strategies of MC: With an internet connection, the consumer can be anywhere in the world and he can have his custom apparel delivered to his house. This is possibly one of the most energy intensive and wasteful aspects of MC, however. In MP transcontinental distribution can be shipped in very large bulk, sometimes filling entire shipping containers, which is, according to the US Department of Energy, the most energy efficient method of large-scale transportation (Battles, 1999). In addition, because the shipment is not directed at individual consumers, there is not a need for expedited delivery. In MC, however, even with weekly aggregated orders, bulk of this quantity is not yet commonly achieved, not to mention that there is the need for expedited delivery which thus requires air shipment, which is the most energy intensive method of transcontinental distribution (Battles, 1999).

We did find one case where a MC manufacturer was very aware of and avoided the energy intensities of a long range distribution infrastructure. For example, Bivolino, who operates two manufacturing facilities in Eastern Europe,
intentionally limited its distribution range to less than 2,000 km and will not ship to overseas customers (Byvoet, 2009).

Perhaps the clearest point of energy savings found in MC distribution of men’s dress shirts over MP is at the point of sale. In our documented examples in the first section and for the general analysis of this paper, we distinguished MC from MP in terms of online retail and bricks-and-mortar retail, respectively. While this is not always the case, as mass produced shirts can be purchased online and MC shirts can be purchased offline, we found our distinctions and definitions to be most commonplace in practice and thus relevant for drawing conclusions.

For MP, where the final product is displayed and ready for purchase at a retail store, there are numerous sources of embodied energy and material use in action. First, and most apparent, is the energy needed to operate the building, such as lighting, heating, cooling and electricity. While these costs are absorbed by and spread out across many other products that the store might sell, we found in some cases that products can sit on the shelves for months, if not entire seasons at a time, before it is sold. Another, more subtle, source of energy utilization found in retail stores is the embodied energy of the display fixtures and other physical materials needed to market and present the product. While there are many strategies available to lower and offset the costs of building operation and product marketing, this source energy is never consumed during the online MC process.
Lastly, perhaps the least understood, and yet possibly the most energy wasteful component in the product life-cycle of MP, is the energy utilized by the consumer in his travel to and from the retail store to purchase the dress shirt. Building from our assumption that the average American male consumer will drive his own automobile three to five miles to the nearest retail location to purchase a dress shirt, we believe this is one of the key factors that make MP significantly more energy intensive than MC. According to a recent study by the Logistics Research Center comparing the environmental impacts of conventional vs. online shopping, “when a customer shops by car and buys fewer than 24 items per trip…the home delivery will emit less CO2 per item purchased” (Edwards, 2009). They found that on average, conventional shopping trips emitted 4,274gCO2; whereas delivery from online shopping only emitted 181gCO2 (Edwards, 2009). There are many other factors that contribute to this assumption and should be carefully considered in further research, including these questions: Is the consumer making a single and special trip to purchase the dress shirt? Are there other passengers during the trip who might help absorb the total energy costs?

Post Transaction & Consumer Experience
The final stage in the product life-cycle of a men’s dress shirt that we examined was for the period after which the consumer had decided the purchase (or not purchase) the shirt. Within this life-cycle stage we outlined 3 post-transaction scenarios for both mass customized and mass produced shirts, include: use pattern, returns, and resale/redistribution. While some of these scenarios are very
intangible, we discovered evidence that strongly supported our hypothesis and made it clear that mass customization is indeed less energy intensive.

Use Pattern

Fit, function and personalized style are the key tenets of MC that distinguish it from MP particularly after the customer starts utilizing the product (Piller, 2006). Combining these characteristics of MC translates to better clothing ergonomics, greater comfort, and a reduced need for additional tailoring (i.e., more traveling). We also expect this to translate into more frequent utilization and a higher level of customer care for MC products, thus reducing the customer’s need for purchasing more shirts and subsequently decreasing the overall negative environmental impacts found in manufacturing and distribution. For example, Spreadshirt.com, a MC web platform for making consumer products such as casual apparel, bags, and cups, conducted a survey on its t-shirt customers and found that 36% said they would wear their custom T-shirt every time that it was cleaned (Eggers, 2009).

Returns

One of the largest energy and material use advantages of MC over MP is in product returns. According to a 1999 survey of apparel manufacturers conducted by the Reverse Logistics Executive Council (RLEC), the average return rate for MP apparel was 20%, and in some cases, where MP shirts were sold online, the return rates were as high as 40%. In stark contrast to these rates, in our industry

Interviews we found that MC apparel returns ranged from 1% - 4% (Byvoet, Possen, Eggars, Teel, 2009). This reduction has dramatic implications for reduced energy use because product returns create additional customer travel to and from the original retailer. From the RLEC survey, it was reported that over one-half of the MP shirt returns were caused by defective or damaged goods, and of those, nearly 30% were thrown out and destroyed. On the other hand, MC manufacturer, Bivolino, reports approximately 4% returns, where 50% of the total returns can be repaired and returned back to the user and 25% are remade, leaving 1% that are discarded (Byvoet, 2009).

From our interviews, we found that some MC manufacturers require customers to first send the shirt back for analysis and verification, before any additional action is taken. This requires additional energy for transportation and shipping, however, it can eliminate the possibility of over-production by pin-pointing small manufacturing errors that can easily be repaired, instead of replaced. MC manufacturers can further reduce the transportation and shipping energy costs by co-locating analysis with production. After the initial purchase and the associated first purchase time costs, MC producers should expect even lower returns with better customer databases, adjustments made by the customer and MC provider, and better body scanning technologies.

Markdowns / Re-sales & Redistribution
In addition to the high level of MP apparel returns and its energy utilized, an equally large amount of energy and materials is utilized for MP products that are
re-sold and re-distributed in secondary markets. In fact, according to Sander’s 1996 MP apparel retailer interviews, 42% of the product value is lost due to end of the season mark-downs and discounts on apparel that was not initially sold. Comparatively, in MC, there is no need for mark-downs and discounts as there are no extra products manufactured. In MP, when product still remains on the retail shelves even after significant mark-downs, an additional distribution cycle is set in place for secondary markets such as retail outlet stores. While this can effectively recover a portion of the lost value, we see this as a large and redundant source of energy and material use. Clearly, MC has distinct advantages over MP in this stage of the product life-cycle due to more integrated customer involvement and interaction, more precise return and repair capabilities, and the absence of redundant distribution cycles.

Conclusion and Future Work
In our research we have identified a number of key areas where we can compare and contrast MC and MP strategies and present anecdotal evidence including retail experience, inventory, cutting/sewing, packing, distribution, packaging, and returns. This initial comparative research of a portion of the energy and environmental impact on MC and MP product lifecycle leads us to believe there are significant benefits in thoroughly expanding and scientifically quantifying this analysis. Our current research was focused on processes that can be measured through material waste, transportation, embodied energy, time, and labor costs. However, the more difficult to measure purchasing behavior and use patterns will
be extremely valuable in ultimately determining their impacts on the entire product lifecycle. Determining whether or not a piece of purchased clothing is used frequently, never, just one time, or even “re-gifted” potentially has dramatic impacts on the energy use. Differentiating the affect of MC vs. MP clothing these areas will be an additional area to research.

The main result of our research and conclusion we have come to is that mass customization, over the entire product life-cycle is indeed more energy and resource efficient than is mass production, however, where these energy savings were found within the life-cycle came from surprising and subtle places. From the outset we assumed that certain aspects of both systems (MC / MP) were more energy and resource intensive, such as the manufacturing technique of single ply cutting found in MC, or the large inventory requirements for mass production lines. Similarly, we knew energy and resource savings would be found in both systems, such as large volume shipping found in MP, or the little-to-no need of warehousing and physical retail space for MC. For most of these examples the energy intensive processes either negated the energy savings, or the processes were simply shifted upstream or downstream within the product life-cycle. For example, we found that upstream shift was commonly the case for material inventory in mass customization – essentially this means that the same amount of total material is still in the product life-cycle; it is just shifted to another party.

To our surprise, where we found the most energy and resource inefficiencies in MP systems, and which led us to our conclusion that MC embodied less energy,

was at the end of the product cycle – when the product was in the hands of the consumer. Specifically, this was the case when the consumer either decided to return the mass produced shirt, or the shirt was not purchased at the original retail location and had to be re-distributed.

Lastly, researching the capital investment costs of setting up an MP or MC manufacturing facility, website, and distribution network, will also be a key factor in understand the total product lifecycle. The question of total space per unit of end product and overall energy utilized product activities like design and marketing will need to be considered. Cooperation from MC and MP manufacturers will be crucial in the next phases as access to detailed knowledge and data will provide the basis for a robust framework and methodology. Our eventual goal is to establish a new area of research called “Green Customization” which focuses on the creation of highly customizable products and services with green performance benefits.

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References


Early, J. (2009), Telephone interview with Judson H. Early, Corporate Vice President, Chief Technology Officer of TC2, a provider of solutions for the sewn products and related soft goods industries specializing in technology development and supply chain improvement. http://www.tc2.com/index.html


Luber, M. (2009), Telephone interview with Marybeth Luber, CEO of Archetype Solutions, Archetype-Solutions, a provider of end-to-end solutions for mass customization technology and services for the apparel industry. http://www.archetype-solutions.com/


