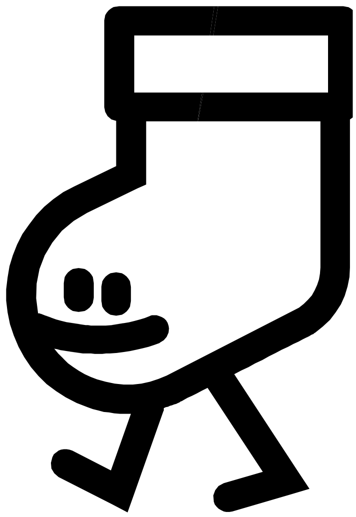
Sorting Socks



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Contents

Introduction and Abstract

"One can never have enough socks."

– Albus Dumbledore (Rowling and GrandPré, 1998)

It struck me one day, while meticulously sorting through a mountain of underwear and socks that I thought "there must be a better way." This inspired me to think about this problem more deeply, and apply a more rigorous analysis. This analysis will primarily focus on socks and the entire process of sorting socks, with the aim of improving the sock sorting process through a systems engineering scope.

Using the analysis methods, it was found that an efficient sorting algorithm could be implemented. Other monetary and environmental concerns were also discussed and it was found that there are typically trade-offs. The user could potentially save significant amounts of money if they bought longer lasting socks and used the best algorithm to sort them.

Design and Data Concepts

In order to establish a context for this analysis, some numerical estimation will be made beforehand. If we assume that a person changes their socks daily and washes them as they use them, people could have a minimum of 7 pairs. However, given that many people play sports, work in a business and may wash their socks in sets or other factors, a single person could own over 20 pairs just for themselves. Taking this to a household level, there could be households with over 100 pairs of socks for the family.

Quantitative Methods

The time to wash and sort the socks is also vital. Washing socks is fairly straight forward, but then hanging them to dry individually, taking them off individually, and lastly sorting them could take considerable time. Assuming 160 socks (80 pairs), 3 seconds to hang and peg each, 3 seconds to take each one off, and an extra 15 seconds to find each pair, that's $160 * 3 * 2 + 80 * 15 = 36\ minutes$! That's 36 minutes for *socks* alone!

Of course, there is error in this estimation. Variables such as sock colour, size, amount, lighting, weather (for drying), etc, can influence the time it takes to wash and sort socks. Socks may also be dried in a drier, which eliminates the need to hang and remove the sock from a washing line. This will be discussed further in time analysis.

Qualitative Methods

To complement the quantitative estimation, a qualitative component in the form of a survey was conducted and 20 responses were received. 20 responses were deemed to be an appropriate sample size for this analysis. The data from this survey can be seen in Table 7 in the Appendix.

After receiving feedback from the questions, it was found that some of the questions were slightly ambiguous or slightly misinterpreted. For example, some participants responded with how long their socks would last *between* washes, rather than their entire lifetimes. Hence the questions themselves provided elements of error in the data collection, simply from semantics. However, the survey provided a good basis to the previous estimation, which showed that estimated number of socks (80) was an appropriate figure. The data collected in the survey was also used in multiple of the following topics. Particularly interesting feedback obtained was a common thread of 'laying out' socks, as well as different approaches to washing the socks. These findings will be discussed throughout their appropriate topics.

Analytical Models

As a sock sorting process is a physical procedure, it is a suitable candidate for simulation. MATLAB will be used to simulate sock sorting procedures for the analysis in the report; this is shown in the time and optimisation analysis portion.

Mathematically, if we have N unique pairs, then each sock must be found by picking a sock and finding its partner (i.e. there are no 'same' pairs.) Hence, for N pairs, the number of average worst-case checks would be $N * (N - 1)/4$ (Refer to Note 1 in the appendix to see this derivation). If the categories are reduced, such that there are N pairs with M ≤ N non-unique pairs, sorting will be faster as a given sock can be matched with a sock that it did not originally come with it, but the same type. Note that a 'check' refers to a brief comparison of socks which can be considered a quick glance, etc. This specific instance is shown in the time analysis, but is shown here to outline a model for the simulation (or an expected outcome).

Human Factors

As socks are so ubiquitous in our lives, a large amount of consideration should be given in their sizing and comfort. Currently, there are multiple ranges of sizing for socks for both children and adults, with a range of colours and materials. Bonds, a popular Australian underwear and clothing company, currently manufactures 4 sizing categories for kids, 2 for adult males and 2 for adult females (Bonds.com.au, 2014).

Sorting is only a tedious problem because there is a criterion that separates the socks. A mathematical analysis is presented in the time analysis portion of the paper to explain just how much faster sorting can be with reduced criteria, however, it is obvious that the less colours and sizes etc. there are, the faster the sorting will be (e.g. If all our socks are the same, there is no sorting!)

Human factors, specifically using anthropometrics will look at what size a sock can be to accommodate for the entire male and female adult population, essentially removing the categories for these demographics, indirectly speeding sorting. Table 1 shows critical dimensions for the human foot, which is highly relevant to socks, with each percentile specified.

Table 1 - People's feet dimensions - (Msis.jsc.nasa.gov, 2014)

Foot Length (cm)						Foot Breadth (cm)					
Female 5%	Female avg	Female 95%	Male 5%	Male avg	Male 95%	Female 5%	Female avg	Female 95%	Male 5%	Male avg	Male 95%
21.3	22.9	24.4	25.4	27.3	29.3	8.6	9.3	10	9.0	9.9	10.7

Hence in order to make a single size sock that fits 95% of the entire population, the sock would have to accommodate a breadth range of 8.6-10.7cm and a length range of 21.3cm to 29.3cm. This puts the mean breadth and length of the socks at 9.65cm and 25.3cm respectively. It is likely better to make the sock smaller in order to not produce a loose fit, and then provide a material that can stretch adequately to accommodate for the larger feet.

Conventionally, socks are made from elastic and flexible materials; hence a "One-size-fits-all" sock is most certainly plausible. From the above analysis, Table 2 demonstrates the best sock size for sorting.

Table 2 - Ideal sock dimensions

Foot Length (cm)	Foot Breadth (cm)	Length Stretch requirement (cm)	Length Stretch requirement (cm)
21.3cm	8.6cm	8cm	2.1cm

While Table 2 shows the ideal sock dimensions, a potential issue is material tradeoff. For example, a more flexible sock may not comply with the user's daily task or requirement, for sport (where thicker socks are used) as an example. There could also be a potential issue with 'unisex' one-size-fits-all socks, as the existing convention has socks categorised by gender. There exists no evidence, however, that men's and women's socks differ by shape, so colour would likely be the determining factor in sock choice which is independent of size, of course.

The comfort of socks is somewhat independent of the sock sorting process. Comfort should still be considered, as this can determine overall use of the socks and user experience that comes with them. For example, Bonds' "Ultimate Comfort" "specially designed sport socks feature padded cushions for extra comfort and shock absorption, as well as a mesh open knit for breathability when things get hot." (Bonds.com.au, 2014) While sizing is a contributor to comfort of the sock, breathability and cushioning, as mentioned, could be added to enhance user comfort.

Hence through determining this ideal sock size, the gender and size categories for 95% of the adult population have been totally eliminated. This enhances the user experience in that there are drastically less criteria in the sock sorting process and the procedure becomes more pleasant and less arduous. Not only does this result have a direct relationship with the following topic of time analysis (saving time), but is also heavily related to optimization.

Time Analysis

Time Analysis is the most critical aspect of this analysis. The problem of sock sorting arises because of the criteria to sort by. A PERT (Program Evaluation and Review Technique) chart is necessary for a more detailed look into the entire procedure. This chart will demonstrate the different ways the method can be undertaken and the steps involved, as well as their duration. Figure 1 demonstrates the PERT chart for the two different responses indicated in the survey.

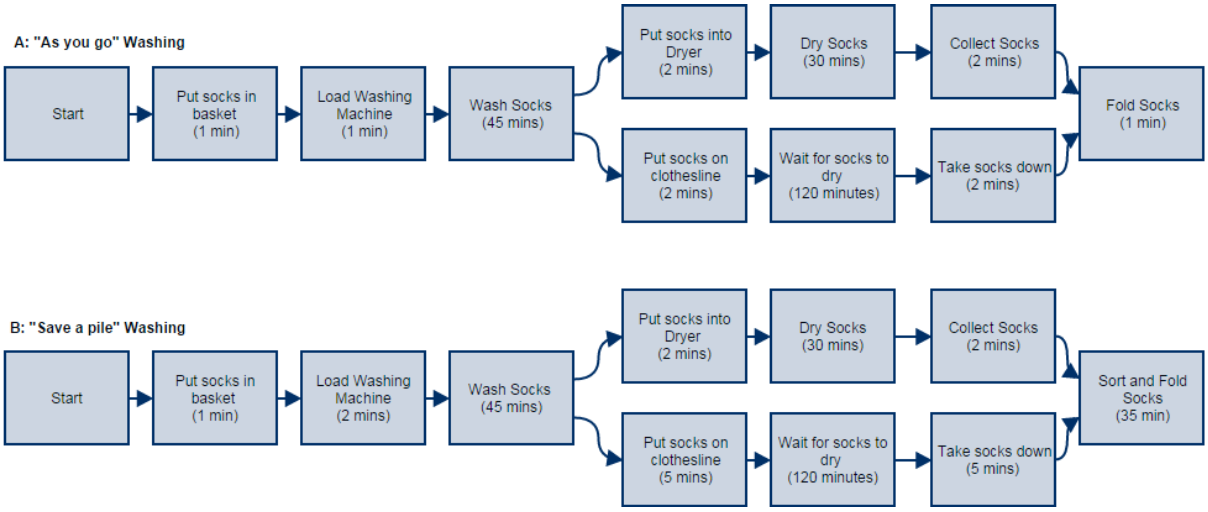


Figure 1 - PERT chart time analysis of sock washing and sorting

As shown in Figure 1, the scenarios "A" and "B" are displayed for washing socks frequently, and washing them in collected piles. The sock sorting process has essentially 3 solutions:

1. Eliminate the problem
    a. Don't wear socks.
    b. Don't wear matched socks.
2. Prevent the problem
    a. Wash socks frequently to eliminate large piles to be sorted
    b. Don't let the socks get mixed so sorting isn't necessary.
3. Fix the problem
    a. Develop a good way to sort the socks.

Not wearing socks is not a reasonable solution as socks are too common. Washing socks frequently to eliminate large piles to be sorted is a good solution to cut time down (as shown in Figure 1 (A)), but this is also resource heavy and may not always be practical. There also exist bags, such as the Australian NoOddSocks™ that contain pockets for the socks to be inserted and then washed, thus preserving their order. This is also a viable solution but an extra cost. And finally, developing a good way to sort the socks is the primary objective in all of these scenarios as it is the final common bottleneck to the procedure outlined in Figure 1 (B). It must also be noted that losing single socks would also severely impact the latter stage of the PERT chart's process, as the user would stall in trying to match a single sock with one that isn't there. This issue was particularly highlighted in the user surveys.

In order to reduce the sock sorting time, two primary outlooks can be taken to do this.

1. Reduce the criteria to sort the socks
    a. This was discussed previously in Human Factors. Have 'same' pairs.
2. Sort the socks efficiently.
    a. Develops a good method to combine them and fold them.

A MATLAB simulation was conducted to see the effect of both increasing the amount of socks, and increasing the number of 'like' socks. (Refer to Note 2 in the Appendix for code).

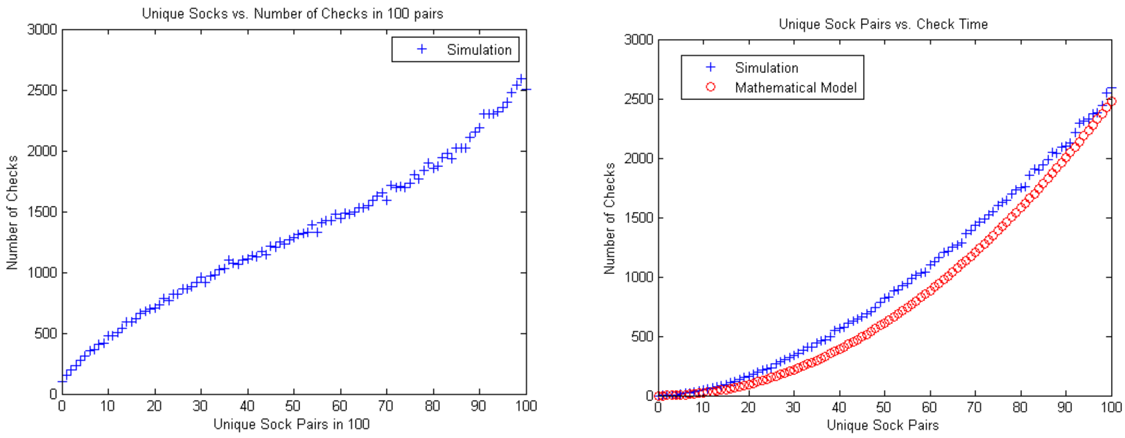


Figure 2 - Sock simulation and checking time

As shown in Figure 2, the simulation shows that increasing the proportion of unique pairs in the socks pile dramatically increases the amount of checks one must do. This scales roughly linearly within 100 sock pairs, but increasing the number of unique sock pairs in general scales with N^2. Hence, a great way to reduce sock sorting time is to have 'the same' socks, and minimise the amount of socks overall. Note that the 'bumpiness' in the figure is inherent in the random variation of the sock matching procedure; each point represents an average of 10 sorts. The PERT chart in Figure 1 identified the bottleneck of sock sorting, and the investigation with MATLAB simulation has shown a quantitative analysis to suggest ways to ultimately reduce sock sorting times. The mathematical model developed previously also fit the simulation extremely well. Algorithms for sorting will be discussed in the Optimisation section.

Energy and Materials Analysis

While not directly linked to sorting socks, energy analysis of socks remains important. In order to investigate the energy consumption of owning socks, many things could be looked at, ranging from the washing machine to the dryer. It was decided that the necessary tool for energy analysis in this report would be an IPCT analysis. As socks do not expend energy in a direct way, they can be thought of as being consumables (through wear-and-tear).

Their embodied energies will be considered for this analysis. In order to proceed, the embodied energy (EE) will be defined as follows:

$$E_{Embodied} = Consumption * \sum \frac{Material_{mass}}{Total_{mass}} * Material_{EE}$$

Table 3 illustrates common sock varieties with their respective attributes. This combines the ideas of a materials audit and an IPCT together.

Table 3 – IPCT (IPAT) with a Materials Audit - Embodied Energy of Socks (Lafitte.com.au, 2014), (Hammond, 2006)

Name	Weight (kg)	Materials	Composition (%)	Embodied Energy (MJ/kg)	Consumption per year	Total Embodied Energy per year
Sports	0.047	Cotton	0.95	143	1	6.73275
		Nylon	0.05	148		
Adventure Long Sock	0.071	Wool	0.8	106	0.5	4.0612
		Nylon	0.2	148		
Anklet	0.047	Cotton	0.8	143	1	6.768
		Nylon	0.2	148		
Wool Tough Toe	0.052	Wool	0.6	106	0.5	3.1928
		Nylon	0.4	148		

The consumption figure shown in Table 3 was a rough estimate to establish the calculations, and the weights of the socks were empirically tested and inserted into the table. The data from the user survey is also consistent with these figures.

As shown with the calculations of the different sock compositions, the sock that reduces the entire system energy consumption is the wool tough toe sock. As seen with the factors above, particularly with the embodied energy, to improve the environmental impact of socks one could:

1. Use socks with high wool content (lowest embodied energy)
2. Make your socks last as long as possible.
3. Buy lighter socks (there is less material overall)

Independently of sock composition, obviously it would also be desirable to use energy-less washing methods such as hang-drying or minimising wastage such as washing with full loads, etc.

Linking this with the Human Factors portion, there may be some conflict between the two solutions prescribed in each section. A 'one-size-fits-all' sock composed of largely wool would be ideal, but may have some challenges with flexibility and fitting all sizes. The user would have to find a trade-off whether they'd prefer to sort socks faster, or be more environmentally friendly. Producing a sock with minimum nylon content that can fit all sizes would be the best solution for both scenarios.

End of Life Issues and Toxicity

As shown in Table 3, the primary materials present in socks are wool, cotton and nylon. Wool does not pose a threat with toxic materials as it is directly sourced from sheep and other animals.

“Wool is a natural and renewable fibre. It is made from keratin. A tough, insoluble protein with a unique structure that gives it a natural resistance to sunlight, water, acids, rot and mildew under most normal conditions. However, at the end of its life, wool will biodegrade in soil, releasing valuable nutrients. Wool is susceptible to attack from a small number of specific insects, however safe insect resist treatments are available to counter this.” (Grundy, 2008)

Cotton Incorporated conducted a comprehensive life-cycle assessment (LCA) of cotton and found that “When the entire cotton life cycle was considered, two phases dominated the impact profile of the LCA: Textile Manufacturing and Consumer Use. The potential impacts from these phases are predominately attributed to energy use during fiber processing, wet preparation and dyeing, and laundering of garments.” (Cotton Incorporated, 2012)

Hence, end-of-life impact of cotton, a naturally occurring substance is minor. Even though cotton can biodegrade easily, it can also “be recycled into wipes for use in a variety of industrial sectors and shredded to be used as mattress infill or into insulation for buildings. Cotton can also be used as a source of raw material for the manufacture of regenerated cellulose fibres either through the viscose or lyocell processes.” (Oakdene Hollins, 2009) This shows that socks with a high composure of cotton are good for cradle-to-cradle applications and general environmental factors.

However, Nylon is the largest end-of-life concern present in socks (this could be reflected from its embodied energy). “In general nylon is not bio-degradable and is therefore unsuitable for composting. Disposal to landfill is regarded as an option; however as a melt spun fibre it is possible to remanufacture the nylon into more fibre or other applications. Fibres produced from re-processed nylon are available.” (Oakdene Hollins, 2009). Hence nylon should be re-used rather than disposed of.

As seen from the summary of the three materials, socks composed of mainly wool and cotton pose no threats to the environment at the end of their lives, and can even be used as raw materials for other processes. Socks with high nylon content should be re-used as much as possible before being discarded. Unfortunately, all the socks present in Table 3 contain some nylon. However, with small quantities such as the sport socks, the end-of-life issues are not significant. This also raises another interesting point, given that sport socks have the highest embodied energy. Once again, there is a trade-off between what is more desirable in terms of EE impact and end-of-life issues. This further suggests that wool is the best option.

In terms of direct sock re-use, there exist many handy ways that socks can be used other than worn. These include (but aren’t limited to)

- Dust rags/ dusting device/ wipes.

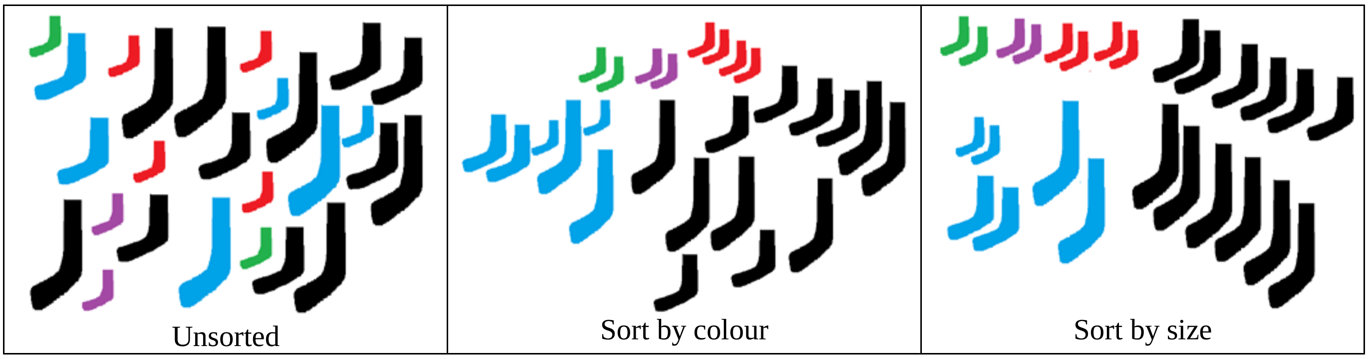
- Protection devices/ cases.
- Toys/ dolls/ puppets.
- Bands/ ties.

Optimisation

As shown in the time analysis component, decreasing the number of socks and increasing the proportion of like socks improves the sock sorting process which scales with N^2 and N respectively.

An appropriate method to sort socks would be using a Radix sort algorithm. This algorithm splits criteria into 'buckets' and then recursively repeats the process for different buckets. As an obvious example, when sorting a mixture of socks, would be to make each bucket a colour. The socks would first be split into piles by colour and then they can recursively be split into other criteria. The following example in Table 4 demonstrates the algorithm.

Table 4 - Sorting Procedure



First all the socks are combined. The socks are then sorted by colour. As seen in Table 4, this immediately combines the green, purple and red socks and they're complete. The blue and black socks are then sorted by size. This method not only ensures a convergence to everything being sorted, but will identify odd socks quickly and it provides a systematic way of doing so. This procedure can be outlined as follows in Figure 3

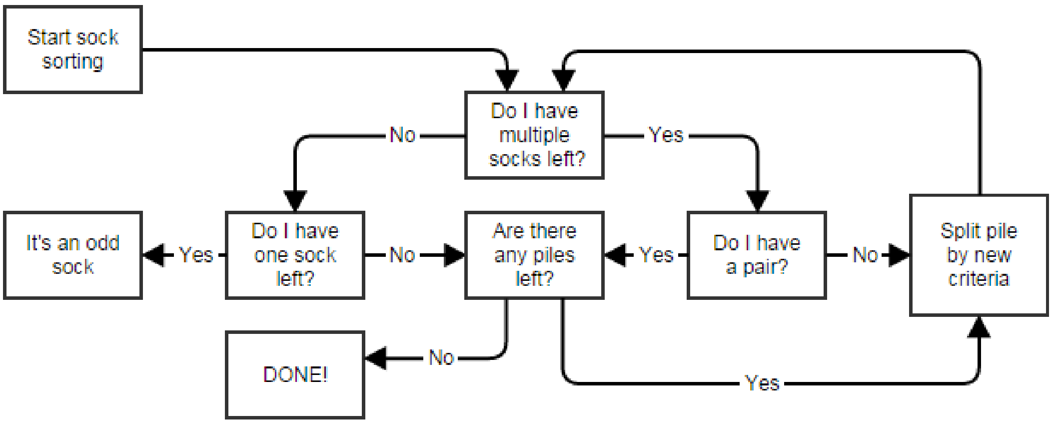


Figure 3 - Sock Sorting Algorithm

The worst case of sorting in terms of N pairs of socks is kN, where k is a constant (depending how many times you need to sort). This procedure is up to an order of magnitude faster than the 'naïve' procedure outlined in the time analysis portion, and it can be undertaken concurrently!

Of course, the algorithm doesn't need to be followed until there is exactly one pair in a pile, but to when a human can distinguish a pair quickly enough from a larger pile to move to the next pile.

Thus comparing $kN = N^2$(old sorting method to new sorting method), the best method for sorting socks changes when $k = N$,or more practically, when the number of ways to sort the socks (colour, size) (k) is equal to the number of pairs of socks (N). When $k < N$, then $kN < N^2$, hence using the algorithm outlined in Figure 3 is better. When $k > N, then\ kN > N^2$, hence using the normal sorting algorithm (pair-wise comparison) is better. This is illustrated in Figure 4.

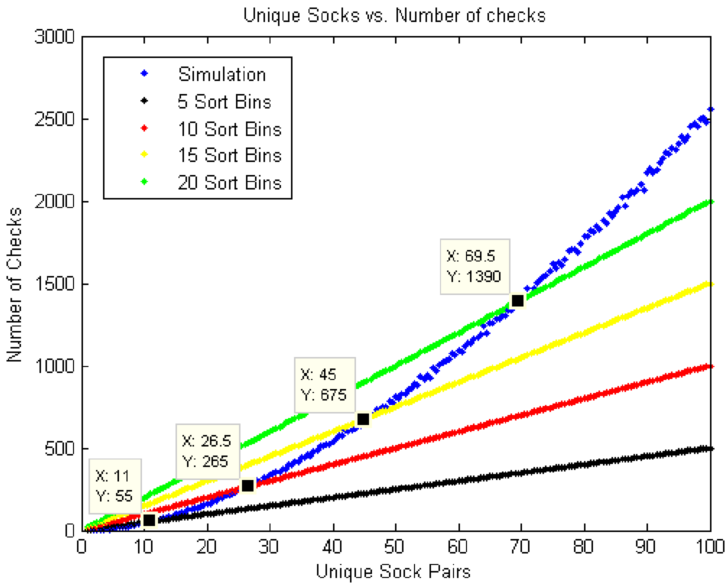


Figure 4- Comparing sock sorting algorithms

As seen, the more sock sorting criteria there are, the more socks are needed to exploit the sorting process. For example, if there are less than 45 types of socks, the regular sorting algorithm is necessary, but if there are more than 45, the (linear) algorithm in Figure 3 is better. This is essentially a 'pay-back' period for the socks with money, but through the time analysis. However, this payback period is not at a fixed point, and alternates depending on the point in time; this is shown later on in Figure 5 in the cost analysis.

Another empirical observation which is confirmed by the survey data is the option of parallelism. The previous simulations assumed that humans can only look at one element at a time, which isn't totally correct. Some users indicated that they spread their socks out over a bed or table. This facilitates observing a large portion of socks concurrently, and can lead to immediate matches for bright, large or obvious socks. Once this benefit has been expended, it is them recommended to move onto a better or systematic procedure outlined in either of the sorting algorithms present in this analysis.

Cost Analysis

There are multiple cost considerations regarding sock ownership. These are primarily the acquisition cost and maintenance costs. Acquisition cost for socks does not vary much between common household brands, and maintenance costs (washing) can be thought of as the same for any sock type.

The cost analysis will look at time saved in sorting, and equate this to the potential monetary saving. As seen in Figure 4 of the optimisation section, depending on the sorting algorithm and the total number of socks, the time spent sorting socks may vary. In this case, it is reasonable to assume that money scales linearly with time (i.e. if you make $100 in 2 hours, you make $200 in 4 hours).

Table 5 - Cost of sorting time

	Pair-wise sort			5 Bucket sort			10 Bucket sort			
Sock Pairs	Checks	Time (m)	Potential $	Checks	Time (m)	Potential $	Checks	Time (m)	Potential $	Money Saving ($)
0	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0.00
5	13	0.13	0.04	25	0.25	0.08	50	0.50	0.17	0.04
10	47	0.47	0.16	50	0.50	0.17	100	1.00	0.33	0.01
15	99	0.99	0.33	75	0.75	0.25	150	1.50	0.50	0.08
20	167	1.67	0.56	100	1.00	0.33	200	2.00	0.67	0.22
25	244	2.44	0.81	125	1.25	0.42	250	2.50	0.83	0.40
30	334	3.34	1.11	150	1.50	0.50	300	3.00	1.00	0.61
35	434	4.34	1.45	175	1.75	0.58	350	3.50	1.17	0.86
40	552	5.52	1.84	200	2.00	0.67	400	4.00	1.33	1.17
45	668	6.68	2.23	225	2.25	0.75	450	4.50	1.50	1.48
50	807	8.07	2.69	250	2.50	0.83	500	5.00	1.67	1.86
55	959	9.59	3.20	275	2.75	0.92	550	5.50	1.83	2.28
60	1114	11.14	3.71	300	3.00	1.00	600	6.00	2.00	2.71
65	1248	12.48	4.16	325	3.25	1.08	650	6.50	2.17	3.08
70	1412	14.12	4.71	350	3.50	1.17	700	7.00	2.33	3.54
75	1603	16.03	5.34	375	3.75	1.25	750	7.50	2.50	4.09
80	1746	17.46	5.82	400	4.00	1.33	800	8.00	2.67	4.49
85	1981	19.81	6.60	425	4.25	1.42	850	8.50	2.83	5.19

Table 5 demonstrates the possible cost of time for sock sorting at 0.6s per check and a $20 wage. For example, to sort 85 pairs of socks would take roughly 20 mins at $6.60 for the pairwise sort. Equivalently, this would cost $1.42 for the 5 bucket sort (if appropriate), and hence a potential saving of $5.19 would result. Over a year, assuming weekly washes, this sums to $270. Hence, with an appropriate sorting method, one could save $270 yearly simply from reducing sorting time alone.

There are several notes that should be taken. Firstly, this figure is for 85 pairs. The less pairs per wash means less potential money is saved from sorting. For example, at 20 pairs, the potential saving is 22c which is fairly negligible. Also, changing the parameter of time/check changes the potential money saved. Faster sorters will save the most money. This relates to the optimisation's findings of parallelism; spreading socks on a table will reduce time per check which will intern reduce the total time, which saves money. Earning a higher wage will also cost one more money sorting socks, but this implies that a higher wage means one's time is more valuable overall.

Considering human factors, generally more expensive socks are more comfortable or suit a particular requirement. These considerations such as material and overall build quality influence the lifetime of the socks.

Table 6 - Ongoing costs of sock replacement (Lafitte.com.au, 2014)

Name	**Weight (kg)**	**Composition (%)**	**Cost ($)**	**Consumption per year**	**Total Embodied Energy per year**
Sports	0.047	0.95 0.05	6.95	1	6.73275
Adventure Long Sock	0.071	0.8 0.2	16.95	0.5	4.0612
Anklet	0.047	0.8 0.2	9.95	1	6.768
Wool Tough Toe	0.052	0.6 0.4	13.95	0.5	3.1928

These prices are shown through time in Figure 5.

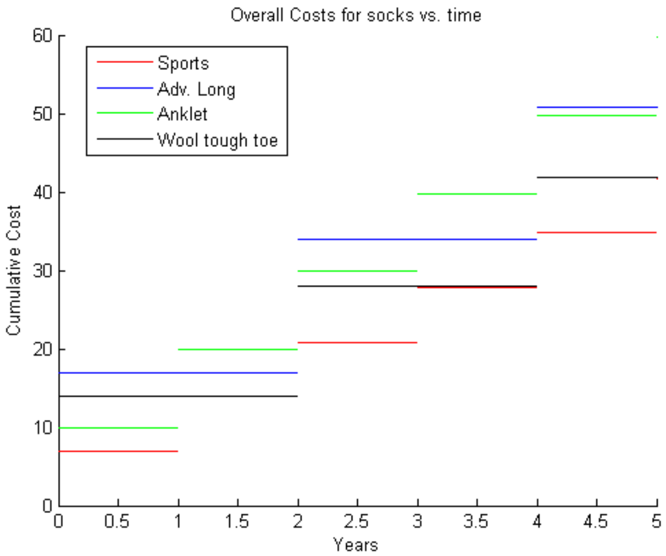


Figure 5 - Cumulative Costs of socks

As seen in Figure 5, and outlined in the time analysis, depending on the type of sock bought, the longer term price may change, hence a fluctuating pay-back period. Note that the anklet is initially cheaper than the tough toe, but eventually surpasses the tough toe after a year. Users should purchase socks with this trade off in mind. However, purchasing more socks also effects the total embodied energy (as identified in the materials analysis) and doesn't benefit the environment. Users should also note that better quality socks may be cheaper in the long run in a monetary sense, but also environmentally.

Also worthy of mentioning, this cost analysis is extremely sensitive to external factors such as the user's occupation, gender, washing method, washing chemicals, geographic location, etc. such that determining accurate sock lifetimes is difficult and varies greatly. However, the previous point about environment and monetary concerns still holds.

Conclusion

Through using the systems engineering analysis techniques outlined in this report, the procedure of sock sorting has been improved in a variety of ways. Human factors outlined that a single sock for the entire population would reduce sorting times and introduce a great convenience. Time analysis identified various solutions and preventions to the problem, and highlighted the impact of owning more socks and different types of socks. Energy and materials analysis showcased the materials involved in the manufacture of socks, as well as their net effect on the environment. Optimisation analysis provided the user a better way of sock sorting and suggested techniques to use for sorting socks. Cost analysis stressed that potentially significant monetary savings could be a result from both buying the right type of socks, as well as sorting them efficiently. Overall, this report has made the experience of sorting socks easier, and has highlighted important considerations in buying and owning socks.

Practical advice collected throughout this analysis for sock users is:

- Try and have socks you can share with other members in the household.
- Try and wash socks as often as you can. (Don't save them up in sets.) This reduces sorting time dramatically.
- When sorting socks, spread them out and search with the algorithm described in this report (split by criteria repeatedly). Socks will be found faster.
- Buy socks higher in wool content (or generally better quality) and less nylon content. They will last longer, be more comfortable and better for the environment.
- Do you need to match socks at all?

Bibliography

(Online clothing store)

Bonds.com.au, (2014). *Size Charts | BONDS Australia*. [online] Available at: http://www.bonds.com.au/size-charts [Accessed 16 Sep. 2014].

Bonds.com.au, (2014). *Bonds Mens Ultimate Comfort Low Cut Sock 2pk | Mens Sports Socks | SANL2N*. [online] Available at: http://www.bonds.com.au/mens-ultimate-comfort-low-cut-sock-2pk-sanl2n-06k.html [Accessed 18 Sep. 2014].

Cotton Incorporated, (2012). *The Life Cycle Inventory & Life Cycle Assessment of Cotton Fiber & Fabric*. [online] Available at: http://cottontoday.cottoninc.com/Sustainability-About/Cotton-LCI-LCA-Executive-Summary/Cotton-LCI-LCA-Executive-Summary.pdf [Accessed 30 Sep. 2014].

G.P.Hammond and C.I.Jones (2006) *Embodied energy and carbon footprint database*, Department of Mechanical Engineering, University of Bath, United Kingdom.

Grundy, L. (2008). *Renewable and biodegradable wool*. [online] CSIRO. Available at: http://www.csiro.au/Outcomes/Food-and-Agriculture/Biodegradable-Wool.aspx [Accessed 30 Sep. 2014].

(Online clothing store)

Lafitte.com.au, (2014). Lafitte. [online] Available at: http://www.lafitte.com.au/index.php?route=common/home [Accessed 30 Sep. 2014].

Msis.jsc.nasa.gov, (2014). *Anthropometry and Biomechanics*. [online] Available at: http://msis.jsc.nasa.gov/sections/section03.htm#_3.2_GENERAL_ANTHROPOMETRICS [Accessed 16 Sep. 2014].

(Product Reference)

NoOddSocks product: http://www.nooddsocks.com/index.html

Oakdene Hollins Ltd, (2009). *Cotton Data Sheet*. [online] Available at: http://www.uniformreuse.co.uk/fabric_cotton.html?KeepThis=true&TB_iframe=true&height=560&width=800 [Accessed 30 Sep. 2014].

Oakdene Hollins Ltd, (2009). *Nylon Data Sheet*. [online] Available at: http://www.uniformreuse.co.uk/fabric_nylon.html?KeepThis.. [Accessed 30 Sep. 2014].

Rowling, J. and GrandPré, M. (1998). *Harry Potter and the sorcerer's stone*. 1st ed. New York: A.A. Levine Books.

Appendix

Note 1:

The classic ‘handshake’ problem is the same as sock sorting: All elements need to be checked with each other. Except, the set of socks is reduced once a match is found. Given that the number of “Checks” for N socks is $(N-1)+(N-2)+\cdots+1$ (this is equal to $N\frac{N-1}{2}$), hence the number of checks with removal is $(N-1)+(N-3)+\cdots+1$, which converges to half of the original checks, which is $\frac{N(N-1)}{4}$.

Note 2:

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%% Sorting Socks
% Josip Simunic
function check = sockSort(uniqueSockPairs, sameSocksPairs)
% Let each pair of socks be a pair of numbers.
A = 1:uniqueSockPairs;
B = uniqueSockPairs+1;
% This a pile of sock pairs.
C = sort([repmat(A, 1, 2) ones(1, sameSocksPairs*2)*B]);
ix = randperm(length(C));
% Shuffling the socks.
Bshuffled = C(ix);
check = 0;
for i = 1:length(Bshuffled)-1
    for k = i+1:length(Bshuffled)
        % Don't count for excluded socks...
        if ((Bshuffled(i) == 0 || Bshuffled(k) == 0))
            break;
        end
        check = check + 1;
        % If we match a pair of socks, remove them from the pile.
        if (Bshuffled(i) == Bshuffled(k))
            Bshuffled(i) = 0;
            Bshuffled(k) = 0;
        end
    end
end
end

%% Plotting sorting socks.
% Josip Simunic
clc; close all; clear;
avg = 100;
pairs = 100;
%Going through unique socks, keeping all socks locked at 100.
for k = 0:pairs
    cul = 0;
    for i = 1:avg
        cul = cul + sockSort(k, 0);
    end
    plot(k, cul/avg, '+');
    hold on
    plot(k, k*(k-1)/4, 'ro');
    drawnow
end
title('Unique Socks vs. Number of Checks in 100 pairs');
xlabel('Unique Sock Pairs in 100');
ylabel('Number of Checks');
legend('Simulation', 'Mathematical Model');
```

Table 7 – user survey data

Timestamp	How many sock pairs do you have in your household?	Do you wash your socks as you use them or in sets?	What method do you use to sort your socks?	Do you think the entire process of washing/sorting is tedious/inefficient?	How long does a single pair of socks last you?	Anything else you'd like to add? Frustrations about socks? Ideas?
9/15/2014 17:19:10	40	As they are used	Manually	Yes	1 year	The loss of socks to the washing machine
9/15/2014 17:26:17	50-75	Wash as I use	Just pick one up and try and find the other	Yes	3 months	When u lose one from the clothesline
9/15/2014 17:32:28	40	Save a pile and then wash them.	Spread on the table/floor.	yes!!!	4 months	Make socks last longer. The elastic always degrades and then the sock becomes useless.
9/15/2014 17:52:36	ALOT. like probably 100 atleast lol.	per use with normal washing	sit on couch and lay them out and sort them while watching tv (winter). in summer seasons, normally match them outside on clothes line while taking down clothes (since they are already dry). Socks are folded up and inserted inside themselves using the elastic to keep the pair conveniently matched	massive pain in the arse to sort socks (.. when theres so many)	1 day. sometime half a day	pain in the arse to match similar looking socks and i find that on the odd occasion (1/20) when i take socks out of the draw, they are mismatched. Also, my house has a bag full of unmatched individual socks which accumulate because occasionally only one sock out of the pair makes to the wash - the other is lost under a bed or something. This bag is sorted every now and then to complete unmatched and missing sock pairs over time.
9/15/2014 18:11:43	100	Per use with normal washing	Spread them out and find pairs as we go.	No	2 years	
9/15/2014 18:14:00	A lot	As I use them.	Usually on the couch.	yes but it doesn't do it itself and it's a necessity.	depends. usually my big toe ends up poking through.	There always ones that gets eaten by the machine.
9/15/2014 18:15:30	6	in sets	same type of socks mostly so not much sorting required	pretty happy with it	2-3 wears	after you are done washing just tie pairs of socks together
9/15/2014 18:27:06	OMG maybe 50	As we use them	Sought them as I hang them	Yes	Maybe a couple of months	I don't like socks
9/15/2014 18:40:00	probably 80...?	I was socks as I use them	spread them out on my bed and put matching ones on top of each other until all are matched or no possible matches remain.	yeah	probably 6-12mths	Question: What adjective best describes any sock who is happy, healthy, and has great friends and family? Answer: Very Sockcessful!
9/15/2014 18:41:18	40	With the normal washing	I put them all in a pile, then match them up	i'd be open to a bette process	Lifetime? 1.5 years or so	I have socks with the day of the week written on them.
9/15/2014 19:17:06	30	normal washing	bed spreading ;)	yes	a week	
9/15/2014 19:54:06	Not enough. (~40)	Depends on my sock washing mood. Usually in sets.	Sorting..? What is this you speak of? Chuck em in the drawer.	Tedious, not inefficient	Couple days	Can you wash my socks for me?
9/15/2014 20:20:11	Oh god probably like 60	Wash as they are used	As the clothes are sorted a sock pile is created on the couch, then we pair them and put them into piles for each person	It has to be done	Maybe like 4 years	Omfg I have one sock each from two pairs which are both black but they're slightly different. I think like 3 years ago their partners just both left them so these guys decided to pair up but I hate it coz they don't match but I can't find their real pairs!! :'(
9/15/2014 20:27:08	40	Save up a pile	I pick out the matching ones individually	Yes	2 years	Some socks get used more than others, so favouritism can be found when sorting
9/15/2014 21:19:45	50+	Wash them with regular washing, not separately.	Spread them out on the couch or bed and begin pairing.	Yes	About a year	

9/15/2014 22:09:28	At least 20.	We wash them once a week with the rest of the washing.	I search through until I find the matching pair.	No, I like having the nice pairs as opposed to odd socks.	Two years.	I neither fold nor roll my socks. I find the pairs which I stack and then place them in a draw.
9/15/2014 22:23:08	like heaps. I probably have like 20. And my parents have like 20 between the 2 of them. so 40ish	I don't do the washing any more:0 but they go in the with the normal washing.	I hand pick them out of the basket. It's more special that way.	Yes except when I'm procrastinating	2 days max I swear.	What happens to the ones that go into the washing machine but never come out again? I've been waiting for my left black sock for a few months now. It matched my black joggers and now it's all wrong.
9/15/2014 22:23:09	I haven't counted recently but probably over 100	As I use them	Dump them on the floor and sort them	Yes	I have no idea	Maybe you should come sort my socks for me so I don't have that frustration in my life any more? Socks are taking over. Help!
9/16/2014 22:35:16	~20	In sets with normal washing. So I just throw in a weeks worth of socks with my weekly wash	Put them all on the bed and then group them	Yes	1 day before washing, 2 years of total use	I hate when they stretch and get saggy
9/17/2014 21:25:50	About 20	I wash the socks as I use them with all my other clothes	After sorting out all my other washing I put them on my bed in a pile and then go through them, finding pairs and putting aside single socks	Yes	1 Day	Can the sock gnomes please return my lost socks