# Universally-Designed Grocery Self-Checkout Systems 

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## 1 Introduction

Customer awareness and use of self-service systems is growing. Most customers are now familiar with making bank transactions through an ATM and checking themselves in at the airport. Suppliers have begun to extend these systems to the retail domain-popularly, through grocery checkout lanes that allow shoppers to scan, bag, and pay for their items with little or no employee assistance. However, customer acceptance of these systems has been slow, and many shoppers have rejected them altogether. Additionally, the systems are poorly optimized for customers with physical disabilities. This report explores a redesign of a grocery selfcheckout system with an emphasis on optimizing its physical design to be more ergonomic and usable, especially for users with physical disabilities.

### 1.1 Background

Self-checkout systems provide a potential cost savings to grocers, because one employee can typically handle up to four self-checkout systems. They also allow for grocers to both adjust for demand fluctuation without adjusting employee schedules and help to provide consistency in service regardless of employee mood (Weijters, Rangarajan, Falk, \& Schillewaert, 2007). They provide theoretical benefits to consumers as well: a fundamental portion of the population that prefers not to interact with human employees in retail. Very early research indicated this is anywhere from 5 to 29 percent of customers, depending on the service scenario (although grocery shopping was not among the six scenarios surveyed) (Bateson, 1985). Additionally, they can save shoppers time and allow them to make discreet purchases. Today, most self-checkout systems are produced by either IBM or NCR, and they cost from $\$ 75,000$ to $\$ 100,000$ for a set of four lanes. A full diagram (including measurements) of the particular self-checkout system used in this report's task analysis and user study can be found in Figure 1.

Although no study of self-checkout acceptance specific to the grocery domain has been


Figure 1: Design and components of the self-checkout system examined for the user study undertaken, there is an extensive literature on self-service technologies in general; they mostly explore determinants of self-service technology acceptance (Childers, Carr, Peck, \& Carson, 2001, Curran, Meuter, \& Surprenant, 2003, Dabholkar \& Bagozzi, 2002). They reference psychological studies to support their determinants, notably the Technology Acceptance Model theory (Davis, 1985), which argues that technology acceptance directly reflects the strength of attitudes and intentions towards using that technology. Expanding on this, Childers and his colleagues (2001) conducted an extensive survey of self-checkout users and confirmed that four attributes of the system are significantly responsible for customers' attitudes about the systems: perceived usefulness, perceived ease of use, reliability, and fun associated with using the system. For this redesign I have largely explored how we can improved the second attribute, perceived ease of use.

Universal design is a term coined in an architecture magazine in 1985 by Ronald L.

Mace, who has spent a lifetime pioneering more egalitarian physical access. The concept can be traced to the architect Selwyn Goldsmith, who in the 1960s proposed the now-familiar street-level curb height (Goldsmith, 1997). It refers to "the design of all products and their environments to be usable by all people to the greatest extent possible, without the need for adaptation or specialized design" (Mace, 1985). In addition to visible physical disabilities, physical challenges can include aging effects and extreme anthropometric ranges. In aggregate, $17.5 \%$ of the United States can be classified as having a functionally-limiting disability, and a further $7.8 \%$ possess a severely-limiting disability (Kraus, Stoddard, \& Gilmartin, 1996).

## 2 Task Analysis

Initially, I planned to explore more general human factors problems with self-checkout systems, likely those present in the displays and controls, and I planned my task analysis accordingly. The main task involved was using the self-checkout system to pay for groceries; this essentially boiled down to a subtask for each item the user has purchased involving scanning and bagging, and a second subtask of paying for the groceries the user has purchased.

The task analysis with a full list of actions, decisions, and errors is presented in Appendix $B$ on page 14 . During the task analysis, I began to notice some of the anthropometric human factors issues present in the scanning and bagging subtask (and, to a lesser extent, in the payment subtask). Notably, I identified the following issues:

- Since every item must be scanned and bagged sequentially, users must take one item from their cart, scan it, bag it, and then repeat the process. Depending on cart placement, this can involve rotating more than $120^{\circ}$ for each item.
- Bulky and/or heavy items cannot easily be self-scanned, as there is no detachable hand scanner. Users must lift those items from their carts or baskets, scan them, and then place them somewhere in the bagging area as there is no 'skip bagging' software option.
- Items for payment are not functionally grouped. The cash and coin acceptors are at an average non-wheelchair user's shoulder height, but the change dispensers are at her approximate knee height.
- The small space for bagging and scanning does not promote clutter avoidance. A user may need to shift all of his already-bagged items to accommodate a new item if the bagging task is not planned in advance.

For my user studies, I planned to pay special attention to these anthropometric and workspace design issues, but I also noted any other relevant human factors issues as they arose.

## 3 User Study

I asked two users to think aloud as they used a self-checkout system at a local grocery store. Both had used self-checkout systems in the past, but generally do so only rarely to occasionally. Both were in their early twenties and in full physical health, and both paid for over a dozen items and used a shopping cart. Full profiles of both users are in Appendix $\mathbb{C}$ on page 17.

### 3.1 Notes from the first user

The first user (U01) is male and of average height ( $68^{\prime \prime}$ ). He scanned 17 items. ${ }^{1}$ one of which required looking up the product and weighing it. He made a few errors that I had predicted might occur in the task analysis, including attempting to skip bagging, attempting to scan two items sequentially without bagging the first, and failing to understand coupon input (which required an attendant override).

[^0]
### 3.2 Notes from the second user

The second user (U02) is female and of above-average height ( $70^{\prime \prime}$ ). She completed two transactions sequentially (some items were personal and some were for later reimbursement), the first with five items and the second with seven items. During the first transaction she purchased one produce item which required product lookup and scale use. She was generally more careful than U01, waiting for visual feedback that each item had been scanned before bagging, and noting in more than one instance her uncertainty about how the machine would act if she tried to do things out of a certain order. She made no major errors and followed the steps given in my initial task analysis, although she did try to begin her second transaction before the first was fully completed, prompting the system to give her auditory feedback to wait. She also failed to place her produce entirely on the scale at first, and the system seemed to wait until she realized her error.

### 3.3 Design ideas from the user study

While neither user stumbled over the anticipated anthropometric issues from my task analysis, they did reveal that their level of past experience with self-checkout systems influenced their current decision-making. For instance, U02 (who uses the self-checkout systems "occasionally") planned out a bagging strategy in advance, separating hot and cold items, because she didn't like having to later shift them around. She also paid with a card in part because "cash is a hassle," but she elaborated that she thinks it takes a long time to insert cash into the systems. U01, on the other hand, uses self-checkout systems rarely (he commented that it was the first time he had tried one at this particular grocery chain), and he grew slightly more frustrated by the onerous task of moving back and forth from cart to scanner to bag. He also mentioned disliking losing track of his place on the screen's virtual receipt as it grew because he was forced to move his head back towards the cart and look away from the screen while doing so.

With this last idea in particular in mind, and also prompted by the sight of a shopper
using a mobility device as I left the store that day, I began to wonder how supportive selfcheckout systems are of such mobility devices and of physically disabled users in general, and this led my redesign process.

## 4 Redesign

After recording data on the various heights, widths, and depths of the grocery self-checkout system (a front view of the system, annotated with measurements, is available in Figure 2 on page 12, a top view is shown in Figure 3 on page 13), I gathered various anthropometric data on both wheelchair and non-wheelchair users (as well as data from my two physically able users), in an effort to envision a redesign that is both equitable in the varieties of physical ability it can support and flexible in that it can accommodate wide anthropometric ranges (these principles of design are adapted from the nine principles of universal design for instruction (Scott, Mcguire, \& Shaw, 2003)). The data are collected in Table 1. Any redesign has the constraint that it cannot be uncomfortable for physically able users while adjusting to be useful to more populations.

Table 1: Anthropometric data (in inches) for wheelchair (W) and non-wheelchair (NW) users, as well as for the two users studied. Sample sizes were $n=46$ wheelchair users and $n=200$ non-wheelchair users (Bajaj et al., 2006; Wickens et al., 2004, pp. 251-2).

| Measurement | $\mu$ for $\mathbf{W}$ | $\mu$ for NW | U01 | U02 |
| :--- | ---: | ---: | :---: | :---: |
| Seated/standing stature (floor to top of head) | 50.5 | 66.2 | 68.0 | 70.0 |
| Overhead reach (floor to proximal interphalangeal joint of <br> middle finger with arm extended overhead) | 63.7 | 80.5 | 82.0 | 85.5 |
| Maximum forward reach (acromial process to proximal <br> interphalangeal joint) | 25.8 | 25.6 | 27.0 | 25.5 |
| Knee height (floor to anterior surface of thigh while <br> seated) | 24.6 | $22.5^{\text {a }}$ | 24.3 | 23.5 |
| Eye height (floor to center of eye) | 45.9 | 62.1 | 63.5 | 66.0 |
| Shoulder height (floor to acromial process of shoulder) | 39.9 | 54.4 | 58.0 | 59.0 |

[^1]After collecting anthropometric data on wheelchair users, I discovered this self-checkout system does not comply with the Americans with Disabilities Act requirements for reach accessibility, which requires that the high side reach for an area accessible only by parallel approach is at most $54^{\prime \prime}$ (United States Access Board, 1991, §4.2). The self-checkout system I studied has a card reader at $55^{\prime \prime}$, a screen extending to $58^{\prime \prime}$, and a coupon dispenser at $59^{\prime \prime}$. Most of those items are at least $20^{\prime \prime}$ removed from the nearest clearance point as well, so even those users who can reach must angle their shoulders at more than $30^{\circ}$ above normal and may need aids such as a pen or pencil. Cumulative exposure to these postures can lead to increased risk of acute shoulder injuries as well as long-term lower back problems, to which wheelchair users are already at greater risk through other daily activities (Bajaj et al., 2006). Below I detail my redesign in parts, referencing the wireframe sketch given in Figure 4 on page 24

### 4.1 Addressing reach issues

As hinted at above, physically disabled users who are constrained to a wheelchair or other mobility device have, on average, very little clearance below their shoulders for performing the scanning subtask and the payment subtask. Additionally, the height of the screen may induce screen glare effects that further limit feedback. However, in designing for a flexible population, we cannot lower the scanner too much, because then we require unnecessary trunk movement in a much larger proportion of the population. To combat these problems, I reduce the scanner height to $27^{\prime \prime}$ and assume that the area beneath the scanner is left clear for knee clearance. This allows for a forward approach instead of a parallel approach, which will also help address rotation issues.

There is one additional feature of the screen design which is difficult to visualize: the display is mounted to the walled area to its left, allowing for angling by users to their preferred eye height. Such an adjustment could easily be actuated automatically through software that identifies a user by loyalty card, a common feature of many grocery stores. I believe this
could help reduce glare effects and trunk movements to see the screen by users at either height extreme.

### 4.2 Rotation issues

Both of the users I studied used a traditional shopping cart with the self-checkout system, for which it is poorly optimized. Since self-checkout systems are often placed next to each other, there is a social expectation to move your cart entirely beyond the scanning area and into the bagging area. This requires a bizarre, often two-handed interaction where users select items from their cart, move backwards to the scanner, and then bag the item near their cart. In my implementation the standard basket shelf remains stationary, but the knee clearance area can be used to store a cart directly underneath the scanner, dramatically reducing the area of work from the system's full $52^{\prime \prime}$ at present to about $30^{\prime \prime}$, depending on the contents of the shopping cart.

### 4.3 Bulky item issues

The current self-checkout system design has no detachable scanner, so users must manually lift each item to the $37^{\prime \prime}$ plateau, only to then move it down again fully half that vertical distance to the bagging area. For a user buying a 50-pound dog food bag or a heavy case of water, the self-checkout system is generally a non-option.

A fairly simple fix lies in the addition of a detachable scanner that, when used, allows the user to skip bagging of an item as well (and perhaps triggers an alert to the attendant to watch for potential shoplifting, as the baggage weight is mostly an anti-theft feature). In my redesign I place this scanner on the backside of the screen, although this is perhaps not the best place for visual affordance to the user that one is available.

For items that are not especially heavy but still fairly unwieldy, I have placed the bagging area at the same height as the scanner for easy sliding of items after they have been scanned. For wheelchair users, this may mean a somewhat awkward reach after completing the task
and removing their groceries, but the handle height of the bagging area should still be less than the mean shoulder height of wheelchair users.

### 4.4 Sequence of use, clutter avoidance, and functional grouping

An especially curious feature of the self-checkout system I examined is the grouping of payment areas-all payment areas are placed to the right of the screen, towards the shopping area of the store, rather than naturally forward and beyond the scanning area. Additionally, the cash and coin acceptors are extremely distant from the cash and coin change dispensers. For wheelchair users, an extreme reach is required to reach any of the payment input areas; for non-wheelchair users paying with cash an unusual reach is also required, sometimes with trunk movement, to reach the change dispensers.

To address these issues, I have grouped all of the payment areas beyond the scanning and bagging areas, as both of those sequences come before payment. Coupons, which in the current system are deposited above the basket shelf area, are now deposited on the far end of the system, in the same physical area as the receipt is dispensed. To avoid clutter users are given nearly $40^{\prime \prime}$ of bagging space, within which they can shift full bags away from the scanner area to decrease clutter. Finally, complementary payment areas have been functionally grouped, so that all of the cash and coin areas are collocated.

### 4.5 Tradeoffs and discussion

The major tradeoff with my redesign is lost space. A current self-checkout system requires only $52^{\prime \prime}$ of width plus some clearance on either side, so most grocers can stack two together in place of a traditional cashier lane. By extending the total width to nearly $69^{\prime \prime}$, there may not be enough room for some grocery stores to support providing an accessible self-checkout lane.

As with any system overhaul, another major tradeoff is cost. These self-checkout systems, intended to be a cost savings for grocers, have exceptionally high upfront costs that
preclude most stores from replacing current technology. However, cost should not be a prohibitive factor in envisioning design solutions, especially when designing for more flexible populations.

This system would require deep evaluation with both physically able and physically disabled users. It must be shown to both objectively reduce the anthropometric issues for physically disabled users and subjectively increase those users' opinions on its ease of use. Additionally, physically able users should subjectively report either a preference for this system design or indifference towards this design compared with the current system.

Finally, because current self-checkout system hardware is proprietary, I have no idea (nor an easy way to learn) how much space the internal workings of the system require. It is entirely possible that knee clearance is simply not an option because a cash repository can only be stored there, for instance.

## 5 Conclusion

Current self-checkout systems provide neither a flexible nor equitable design for all physical abilities. In this paper I have explored redesigning a self-checkout system with a more universal design, and I believe my design addresses the most egregious anthropometric human factors issues present in current designs. However, a major tradeoff of my design (and most likely of any design which decreases functional reach requirements for some of its components) is an increased system physical footprint which-when coupled with the high upfront cost to grocers of purchasing and installing a new self-checkout system-makes it fairly idealistic. Most current grocers would argue that as long as they continue to provide traditional cashier lanes, there isn't a need to replace their self-checkout lanes with new technologies, even if their current lanes are functionally-limiting. However, given the growing interactive kiosk and self-service domain, universal design is still a goal for which designers should strive in the future.

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## Appendices

## A Self-checkout design



Figure 2: Self-checkout wireframe, annotated with measurements (front view)


Figure 3: Self-checkout wireframe, annotated with measurements (top view)

## B Task analysis

## Description of Task

Using a self-checkout system to pay for groceries at a supermarket

## Actions Required

1. Scan club card (if necessary)
2. Subtask for each item:
(a) Lift item from basket or shopping card
(b) Locate UPC code
(c) Move UPC code over scanner (or look up item using product lookup code)
(d) Wait for feedback (an audible scanning sound and/or visual confirmation of the item description and price on the main monitor) indicating item was recorded
(e) Move item into bagging area
3. Press 'finish and pay'
4. Insert any coupons
5. Choose a payment method
6. Insert payment method
7. Take change (if necessary)
8. Remove bags from bagging area
9. Grab receipt

## Decisions Required

1. Where should I place my cart or basket? (on the basket shelf, held in my hands, in front of the scanner area, behind the scanner area, ...)
2. Do I have a club card / is it with me? (yes/no)
3. In which order should I scan my items? (by location within cart, by bagging plan, by price, ...)
4. How should I arrange bagged items? (by hot/cold, by size, by weight, ... )
5. Should I use the menu or enter the barcode number for produce? (either)
6. Do I have any coupons? (yes/no)
7. Which payment method should I choose? (cash, card, check, money order, ...)

## Functions/Goals

Ideally, the self-checkout is quicker and easier than a traditional cashier's line.

## Errors possible

Step 2. Overlook an item or falsely believe it to have been scanned, resulting in accidental shoplifting

Step 2. Selecting the wrong produce item, resulting in accidental overpayment or underpayment.

Step 2(b). Hard-to-locate UPC code on an item, resulting in several rotations of an item

Step 2(c). Cannot get scanner to read a UPC code, resulting in need for employee assistance

Step 2(c). Inability to find produce item on screen, resulting in employee assistance

Step 2(e). Weight mismatch in bagging area, resulting in necessary employee override

Step 4. Trouble using coupons, resulting in frustration and/or employee assistance

Step 6. If paying with cash, you must have machine-readable bills; unreadable bills require employee intervention.

## Human factors issues

Although there are many human factors issues throughout the self-checkout task, I'm choosing to focus on anthropometric issues I have identified:

- Since every item must be scanned and bagged sequentially, users must reach from the cart to the scanner to the bags for each item.
- To this end, there is much rotation required of users who use a cart instead of a basket at the machines. There is no room to leave the cart behind the machine (as that is the bagging area for another machine), so a rotation of more than 120 degrees clockwise is required for each item.
- Bagging is a particularly onerous task, requiring shifting of already-bagged items to squeeze everything onto the bagging area at once.
- Payment method insertion devices are far apart. A cash payer, for instance, must insert cash near their shoulder level and receive change near their knee level.
- Heavy lifting is required for any bulky items; there is no hand scanner.
- Self-checkouts cannot accommodate wheelchair or other mobility device users at allin particular, the screen, money acceptor, and card reader are generally out of arm's reach for a seated person. This is particularly ironic since most grocery stores provide mobility devices.


## C User study

## C. 1 User Study 1

## User and Place

User study 1 involved a 22-year old, male, non-American grocery shopper (U01), shopping in a fully-lit grocery store in Pittsburgh, using a self-checkout machine for approximately five minutes. He rarely uses self-checkout machines, he noted. He is $68^{\prime \prime}$ tall and has a forward arm reach of $27^{\prime \prime}$.

## Actions

1. Scanned club card
2. Subtask for each item ( 17 total items):
(a) Lifted item from cart
(b) Located UPC code
(c) Moved UPC code over scanner
(d) Moved item into bagging area
3. Pressed 'finish and pay'
4. After prompting, tried to scan a coupon.
5. Screen indicated failure ("unknown error"); assistance required.
6. Assistant does something uncertain to activate the coupon, then discards it.
7. Chose payment method "credit card"
8. Inserted card
9. Grabbed receipt
10. Removed bags from bagging area

## Decisions

1. U01 indicated he wasn't sure how to weigh the produce. He decided to consult the screen, which showed an animation of fruit on the scale, and this guided him.
2. U01 decided to use "no particular order" when scanning his items.
3. Upon noting the machine was intended for shoppers with 20 items or fewer, U01 decided to assume he had fewer than 20 items without counting (in fact, he had 17).
4. U01, frustrated with the speed of moving back and forth from his cart to the scanner to the bagging area, decided to test the machine's robustness by scanning two yogurts at once without bagging. The machine complained with audible feedback, but did not freeze his transaction.
5. U01 did his best to adhere to the machine's instructions, despite revealing he was thinking about how frustrating the machine's messages were, particularly with regard to maintaining the proper weight in the baggage area (U01 stated he is not used to bagging all of his groceries).
6. U01 decided to grab his receipt before grabbing his bags, despite the machine being programmed to remind him to do so after removing his bags from the baggage area.
7. U01 decided to place his cart beyond the scanning area, requiring rotation to reach his items and scan them.

## Errors and error corrections

1. U01 did not manage to correctly scan his coupon, and for unclear reasons the machine refused to accept it. This was corrected by employee override, which was not explained (even upon further after-the-fact inquiry with the employee).
2. U01 initially tried to skip bagging of some juice, but received audible feedback (and a locked system) that he had not bagged the item properly. He moved the (now scanned) juice from his cart to the bagging area.
3. In several instances U01 indicated he was uncertain how the machine would behave ("I don't think it will let me do this"), most notably when he tried to scan two yogurts without bagging them individually first. The machine complained ("Please place your scanned item in the bag"), but once he bagged them together it relented.
4. After the first coupon scan failed, U01 almost dropped it into the used coupon slot, believing there to be some kind of coupon scanner in the nebulous depths. He secondguessed himself, but he would have lost his coupon had he not.

## Inefficiencies

1. U01 commented that he didn't realize this particular shopping lane was for shoppers with 20 items or fewer until he had begin checking out, because the sign was placed perpendicular to the screen and was only visible once he reached the machine.
2. U01 had a cart, so he needed to turn almost completely away from the screen to reach for each item.
3. U01 didn't like scrolling to see all of his purchased items on the screen after he had purchased more than 10 items.
4. U01 felt impatient waiting for the assistant to verify his coupon, and wanted a better explanation for why his coupon had initially failed.

## C. 2 User Study 2

## User and Place

User study 2 involved a 21-year old female grocery shopper (U02), shopping in a fully-lit grocery store in Pittsburgh, using a self-checkout machine for approximately three minutes. She made two distinct transactions because some of her items were personal and some were for later reimbursement. She occasionally uses self-checkout machines, she said. U02 is of above-average height for a female, at $70^{\prime \prime}$, and she has a forward arm reach of $25.5^{\prime \prime}$.

## Actions

1. Waited for screen to appear "ready" for her transaction
2. Scanned club card
3. Subtask for each item:
(a) Lifted item from cart
(b) Located UPC code
(c) Moved UPC code over scanner
(d) Waited for visual and/or audible confirmation (the item and price or a scanning noise) that her item had been successfully scanned
(e) Moved item into bagging area
4. Pressed 'finish and pay'
5. Chose payment method "credit card"
6. Inserted card
7. Waited for visual feedback her credit card had been processed
8. Grabbed receipt
9. Removed bags from bagging area
10. Scanned club card (again)
11. Subtask for each item:
(a) Lifted item from cart
(b) Located UPC code
(c) Moved UPC code over scanner
(d) Waited for visual/audible feedback the item had been read
(e) Moved item into bagging area
12. Pressed 'finish and pay'
13. Chose payment method "credit card"
14. Inserted card
15. Waited for visual feedback her credit card had been processed
16. Grabbed receipt
17. Removed bags from bagging area

## Decisions

1. U02 decided to use the self-checkout for two immediate transactions in order to separate the costs of each purchase.
2. U02 decided to place her cart beyond the self-checkout machine scanning area, requiring rotation to reach her items.
3. U02 to follow the machine's instructions despite finding them "annoying and frustrating," so that she wouldn't have any errors.
4. U02 decided to use the visual search menu to find the d'Anjou pears. She also decided to find the item in the screen with one hand while holding the pears in the other, rather than laying them on the scale first, as she was "uncertain" how the machine would act if she reversed that order.
5. U02 used "no order that I know of" in choosing items to scan.
6. U02 decided to use the upper shelf of the bagging area almost immediately, thoughtfully separating cold and hot items into each as she scanned.
7. U02 decided to wait for auditory and/or visual feedback after each item was scanned to make sure it had rung up correctly.
8. U02 decided to pay with credit because "cash is a hassle."
9. U02 grabbed her receipt before grabbing her bags, prompting yet another unnecessary reminder from the software.

## Errors and error corrections

1. U02 tried to begin her second transaction before the screen indicated readiness by scanning an item; it rebuffed her and asked her to wait. She waited, commenting how annoying it was the software knew what she was doing but wouldn't take her input.
2. U02 could not initially get the d'Anjou pear weight to come up on the screen, in part because one pear was off the weight area. She tried several configurations before commenting that "Oh, it's happy now" once she noticed the screen update with the weight of the pears.

## Inefficiencies

1. U02 did not like rescanning her Giant Eagle club card for each transaction, but only because she felt it was onerous to remove it from her purse a second time.
2. U02 said she only uses credit at these machines because "cash is too complex."
3. U02 admitted at several instances that she was not clear on what the machine was doing (for instance, when it told her "system processing" after she selected credit as her payment method), but that she usually waits on the machine to be as careful as possible and avoid mistakes.
4. U02 noted that the visual lookup feature (currently a large, visual matrix of all the produce items available in the grocery store, from which the user selects the product of choice) is onerous and she's never sure if she has the right item.
5. U02 noted that she would never try to use a coupon at the machine, especially if it was particularly valuable, because she'd rather not wait for assistance if something goes wrong.

## D Redesign



Figure 4: The proposed redesign. Depth is reduced to $20^{\prime \prime}$


[^0]:    ${ }^{1}$ There is a store-enforced limit of 20 items on the self-checkout systems, though U01 commented during the think aloud session that this sign was placed above the screen, far too late for him to step out of line just to adhere to policy.

[^1]:    ${ }^{\mathrm{a}}$ This number is approximate because neither source above has a population 50th percentile figure for this exact measurement. In any case, knee heights do not differ significantly among the physically disabled population.

