### 1. Project Introduction & Goal

The purpose of this project was to evaluate how books are returned and re-shelved in the library and to identify ways to reduce unnecessary worker travel. I mapped the current process, calculated walking distances using Manhattan distance = |Δcol| + |Δrow|, and experimented with different improvement strategies. My goal was to redesign the workflow so that re-shelving takes fewer steps, is less tiring, and gets books shelved more quickly.

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### 2. Current State Diagram & Data

In the current system, a worker takes books from the return cart and walks them to their designated shelf locations (FIC, NFIC, FANT, PREP, LABEL, RECYCLE). On average, workers carried only one book per trip, though up to three could be carried at once.

Current Layout:

| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| **A** | FICTION | FICTION | NON-FICTION | FANTASY |
| **B** | RETURN CART (starting pt) | LABEL DESK | FANTASY | RECYCLE |
| **C** | | PREP BIN | | |

**Color code:**
Return cart = blue
Fiction = green
Non-fiction = orange
Fantasy = purple
Label desk = yellow
Recycle = red
Prep bin = gray

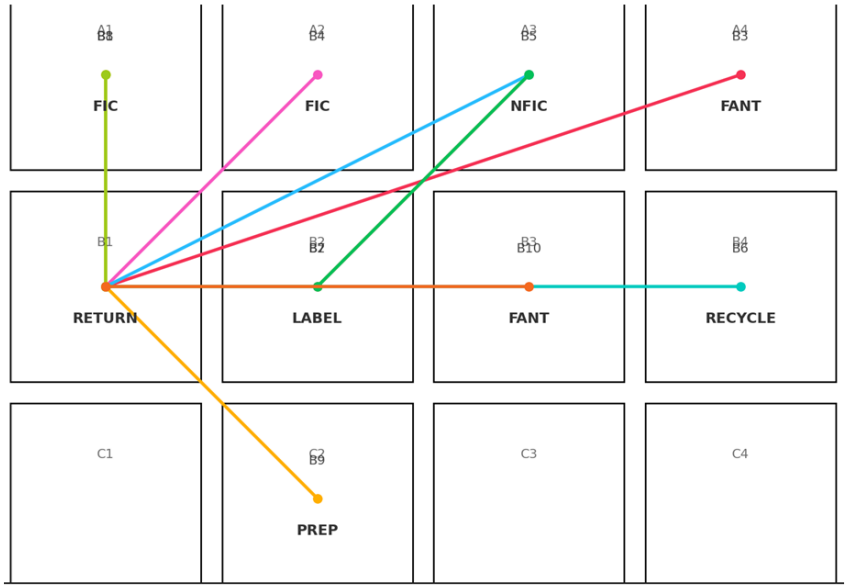
**Coordinates:**
A1 = (1,1), A2 = (2,1), etc.
B1 = (1,2), B2 = (2,2), etc.
C1 = (1,3), C2 = (2,3), etc.

Routes and Distance Calculations (with work shown):

| BookID | Destination | Dest. Code | NeedsLabel? | Route | Steps/Distance | Notes |
|---|---|---|---|---|---|---|
| B1 | Fiction | A1 | No | R → A1 | \|R(B1)=(1,2) to A1=(1,1): \|1-1\|+\|1-2\| = 0+1 = 1 | - |
| B2 | Non-Fiction | A3 | Yes | R → LBL → A3 | R->LBL: \|2-1\|+\|2-2\|=1+0=1 ; LBL->A3: \|3-2\|+\|1-2\|=1+1=2 ; total=1+2=3 | Label before shelving |
| B3 | Fantasy | A4 | No | R → A4 | \|R(1,2) to A4(4,1)\| = \|4-1\|+\|1-2\| = 3+1 = 4 | - |
| B4 | Fiction | A2 | No | R → A2 | \|R(1,2) to A2(2,1)\| = \|2-1\|+\|1-2\| = 1+1 = 2 | - |
| B5 | Non-Fiction | A3 | No | R → A3 | \|R(1,2) to A3(3,1)\| = \|3-1\|+\|1-2\| = 2+1 = 3 | - |
| B6 | Recycle | B4 | No | R → B4 | \|R(1,2) to B4(4,2)\| = \|4-1\|+\|2-2\| = 3+0 = 3 | Damaged → Recycle |
| B7 | Non-Fiction | A3 | Yes | R → LBL → A3 | R->LBL: 1 ; LBL->A3: 2 ; total = 3 | Label before shelving |
| B8 | Fiction | A1 | No | R → A1 | \|R to A1\| = 1 | - |
| B9 | Prep bin | C2 | No | R → C2 | \|R(1,2) to C2(2,3)\| = \|2-1\|+\|3-2\| = 1+1 = 2 | Pre-shelving staging |
| B10 | Fantasy | B3 | No | R → B3 | \|R(1,2) to B3(3,2)\| = \|3-1\|+\|2-2\| = 2+0 = 2 | - |
| | | | | | Total Distance Traveled (One-way): 24 | |

- Baseline path length: 24 steps for a single book drop cycle.
- Bottleneck: Repeated trips to the same locations (especially FIC and NFIC).

This baseline shows that most of the worker's time and energy is spent walking instead of actually handling materials as shown in the spaghetti diagram below:



### 3. Waste Analysis Findings

When I analyzed the current workflow, I identified several key wastes:

- Motion Waste: Workers walk back and forth many times to the same locations like 3 trips to NFIC (A3)
- Batching Inefficiency: Without batching, the total number of trips scales with the number of books. Carrying multiple books slightly reduces trips but still results in walking paths twice or more.
- Distance Issues: Locations like RECYCLE and FANT (A4) were far away

The baseline of 24 steps per book cycle clearly demonstrates a system where most energy is spent moving, not re-shelving.

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### 4. Optimized Design & Results

A. Simple Location Changes (16.7% Reduction)

I thought of two different layout changes and settled with this one because it reduced total distance the most. By switching NFIC (A3) to A2, FIC (A2) to A3, and RCYC (B4) to C1, I was able to reduce the total distance travelled from 24 steps down to 20 steps. This is a 16.7% reduction. While modest, it shows that even small changes can reduce wasted motion.

New Layout and Spaghetti Diagram:

| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| **A** | FICTION | NON-FICTION | FICTION | FANTASY |
| **B** | RETURN CART (starting pt) | LABEL DESK | FANTASY | |
| **C** | RECYCLE | PREP BIN | | |

**Color code:**
Return cart = blue
Fiction = green
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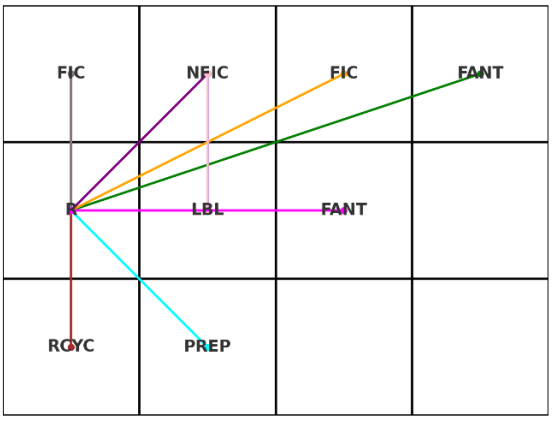
**Coordinates:**
A1 = (1,1), A2 = (2,1), etc.
B1 = (1,2), B2 = (2,2), etc.
C1 = (1,3), C2 = (2,3), etc.




I reconfigured the returns station with a category swap (NFIC closer), moved Recycle to C1, and preserved a straight Return→Label→Shelf path. My new layout reduces long aisle travel (A4/A3 runs) and eliminates over-processing a 3-step Recycle trip by utilizing row C.

New Routes and Distance Calculations:

| BookID | Destination | Dest. Code | NeedsLabel? | Route | Steps/Distance | Notes |
|---|---|---|---|---|---|---|
| B1 | Fiction | A1 | No | R → A1 | 1 | - |
| B2 | Non-Fiction | A2 | Yes | R → LBL → A2 | 2 | Label before shelving |
| B3 | Fantasy | A4 | No | R → A4 | 4 | - |
| B4 | Fiction | A3 | No | R → A3 | 3 | - |
| B5 | Non-Fiction | A2 | No | R → A2 | 2 | - |
| B6 | Recycle | B4 | No | R → C1 | 1 | Damaged → Recycle |
| B7 | Non-Fiction | A2 | Yes | R → LBL → A2 | 2 | Label before shelving |
| B8 | Fiction | A1 | No | R → A1 | 1 | - |
| B9 | Prep bin | C2 | No | R → C2 | 2 | Pre-shelving staging |
| B10 | Fantasy | B3 | No | R → B3 | 2 | - |
| | | | | | Total Distance Traveled (One-way): 20 | |

B. Travelling Salesman Problem (TSP) Batching Optimization (62.5% Reduction)

To push reduction further, I applied the Travelling Salesman Problem (TSP) approach. The TSP is a classic optimization problem where an arbitrary traveler must visit a set of destinations only once and return to the start, while minimizing total distance. In this case, each shelf (FIC, NFIC, FANT, etc.) is a destination, and the worker is the traveler.

By ensuring each location is visited once before returning to the cart and carrying up to 3 books at a time (reasonable), I reduced 10 trips to 4 trips and 9 steps total as color-coded below. That represents a 62.5% reduction from the baseline in total one-way distances.

| BookID | Destination | Dest. Code | NeedsLabel? | Route | Steps/Distance | Notes |
|---|---|---|---|---|---|---|
| B1 | Fiction | A1 | No | R → A1 | 1 | - |
| B2 | Non-Fiction | A2 | Yes | R → LBL → A2 | 2 | Label before shelving |
| B3 | Fantasy | A4 | No | R → A4 | 4 | - |
| B4 | Fiction | A3 | No | R → A3 | | - |
| B5 | Non-Fiction | A2 | No | R → A2 | | - |
| B6 | Recycle | B4 | No | R → C1 | | Damaged → Recycle |
| B7 | Non-Fiction | A2 | Yes | R → LBL → A2 | | Label before shelving |
| B8 | Fiction | A1 | No | R → A1 | | - |
| B9 | Prep bin | C2 | No | R → C2 | 2 | Pre-shelving staging |
| B10 | Fantasy | B3 | No | R → B3 | | - |
| | | | | | Total Distance Traveled (One-way): 9 | |

**5. Conclusion & Reflection**

Through completing this project, I successfully demonstrated how both small changes (locations) and larger routing improvements (TSP batching optimization) can drastically reduce wasted motion and over-processing in library re-shelving.

Here are my own additional recommended operational changes:

1. Move the label station to the return cart or invest in portable label printers.
2. Train staff to batch drops into loops, grouping by genres, and following a route instead of making one trip per book.
3. Cluster the most frequently used shelves closer to the return cart to reduce walking.
4. Add a staging bin near the cart so workers can build batches more easily during peak times.

This project showed me the value of thinking about process design in terms of motion waste. A simple batching strategy gave me only a 16.7% gain, which might not impress on its own. But when I applied routing logic through the TSP, the improvement was striking with over 60% less travel. This structured analysis convinced me that operational layout and worker training can make a major difference without adding staff or expensive technology.