Re-Inventing the Warehouse Using Mobile Robots: Disruptive Technology Change and Challenges in Planning and Optimization

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Supply chain robotics in the news!

Google Acquires Seven Robot Companies, Wants Big Role in Robotics

Amazon Acquires Kiva Systems in Second-Biggest Takeover

I Want It Today

How Amazon’s ambitious new push for same-day delivery will destroy local retail.

One Day, Google Will Deliver the Stuff You Want Before You Ask

Google Seriously Gearing Up To Revolutionize Supply Chain Logistics
Re-inventing the warehouse: algorithm challenges

• Business impact on supply chain – transforming the way goods go from manufacturers to customers

• Algorithm challenges:
  – 3D geometric planning for robot pallet building
  – 3D geometric planning for storage density
  – 3D planning, control, and sequencing for mobile robots
  – Mixed integer programming for warehouse operations
  – 3D geometry and sequence planning for individual item picking
  – Real-time computation
Source to customer supply chain challenges today

- Factory
- Import
- Distribution center
- Order fulfillment center
- Home delivery

Consistent consumer experience

Store formats
Traditionally, robotics focused on manufacturing.

Over 2/3rd cost of goods on the shelf due to supply chain costs.

Even with off-shore manufacturing, supply chain is largely domestic.

Supply chain costs have greatest growth rates:
- Labor
- Workman’s comp
- Fuel

Major supply chain cost drivers:

- Raw material
- Manufacturing people cost
- Manufacturing facility cost
- Manufacturing expense
- Traffic
- Sales operations
- Warehouse
Exploding demand to handle more products

Need space to store

Need more people to pick
Omni-channel Challenge

- Buy anywhere, fulfill anywhere, return anywhere is where we are headed.
- UPS and commSource say:
  - 44% prefer retailer - buy online and pick up in store
  - 62% want to buy online and return items to store
  - 44% of online shoppers abandon shopping carts due to the estimated delivery date
  - 78% pick cheapest delivery
  - 8% of online shoppers fall into the “speeders” segment, <=3 days for delivery, millennial which are a key demographic and social networker
Hardware / software supply chain architecture
Today software mainly used to make humans work faster

Manual case pick & palletize

Manual “pick to light”
Traditional hardware solutions for automated picking

Pallet handling automation

Case handling automation

Item picking automation
Disruptive change: mobile robot explosion!
Why disruptive?

- **Ops cost**
  - High
  - Low

- **Space**
  - High
  - Low

- **Capital cost**
  - High
  - Low

- **Inflexible**
  - Retrofit existing building
  - Change SKU mix
  - Change business model

- **Flexible**
Why disruptive?

• Easy to re-configure
  – Change in SKU mix or velocity
  – Change in business model

• New algorithm challenges
  – Replace fixed hardware with flexible software
  – Leverage research on autonomous mobile robots
Computational challenges for disruptive supply chains

• Challenges to computation
  – Planning & control
  – Density
  – Sequencing
  – Material flow with mixed integer constraints
  – Mixed case palletizing
  – Order clustering

• Emphasis on transformation

Productivity “S” curves
Case study: what we want the service robot to do?

Manual case pick & palletize – 20 million cases per week!
Mixed case palletizing problem definition

- NP Hard bin packing problem
- Cases per line item < 2 (no layers)
- Wide range of packaging dimensions & attributes
- Case dimension tolerance, stiffness
- Build “store friendly” pallets
Handling diverse SKU mix required

Case Induction from Pallets -> Case Storage & Selection -> Mixed Case Palletizing

Grocery / retail

Beverage

Number of SKU's

0  2,000  4,000  6,000  8,000  10,000  12,000  14,000  16,000
Mixed case palletizing: lab and simulation results

Production order: 395 SKU, 476 cases

Aisle number

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Mixed case palletizing: production results
Maximizing warehouse storage density

2D storage wastes vertical space

Symbotic 3D storage topology

Symbotic variable density storage
Optimal density with random vs. fixed access storage

Variable spacing storage

Fixed spacing storage
Storage density for smaller items

- Full pallet
- Variable space cases
- Fixed space cases
- Multi-SKU totes / trays
- Single SKU totes / trays
- Multi-SKU shelf pods
Further 3D storage density problems

• Seasonal changes in SKU mix, in particular at peak
• Dynamic density optimization
  – Replenishment strategies
  – Use of forecast information, impact of forecast errors
  – Food safety and similar constraints
• Individual item storage
  – Optimal sizing of compartments
  – Replenishment strategies when few compartments are empty
Sequencing biggest challenge to system throughput

Truck loading

Robot palletizing

Batching for customer orders
Sequencing with autonomous robots

Input sequence 1
1 2 3 4 5

Output sequence 1
5 4 3 2 1

Output sequence 2
5 4 3 2 1
What we want the robot to do?

- Localize & navigate
- Manipulate workpiece
- Sense environment
- Sense workpiece
- Diagnose faults
- Perform tasks
- Autonomous recovery
- Coordinate with other robots

N * 100’s
Mobile robot planning & control

- High throughput
- Adapt to different supply chain models
- Robust handling of anomalies
- Scalable to large robot fleets and mass storage
Interface to warehouse information systems

Warehouse Management System (WMS)

Warehouse control layer

- Pallet Truck Unload
- Mixed Case Layer Pick
- Pallet Storage
- Case or Tote Storage

- Dead Stack Truck Unload
- Dead Stack Truck Load
- Mixed Case Palletizing
- Break Pack “Each Pick”
Re-inventing the warehouse. Re-imagining the supply chain.
Use of dynamic and fixed agents

Customer data

- Shipment orders
- Outbound pallets
- Replenishment pallets
- Replen fork trucks

Dynamic agent creation
- Conventional pallets
- Automated pallets
- Robotic pallet cells
- Symbotic fork trucks

Fixed agent resources
- Conventional fork trucks
- Outbound truck loads
- Outbound dock doors
- Automated pallets
Warehouse material flow algorithm problems

- Optimal SKU storage allocation choices
- Optimal pallet to case storage replenishment
- Optimal SKU storage allocation choices
- Optimal flows between storage and pick locations
- Optimal shipping & receiving schedules

Diagram:
- Pallet Truck Unload
- Dead Stack Truck Unload
- Pallet Storage
- Case or Tote Storage
- Dead Stack Truck Load
- Mixed Case Palletizing
- Break Pack “Each Pick”
Mixed-integer programming constraints

- Truck loads
- Cases per pallet
- Cases per layer
- Pallets
- Truck loads

- Pallet Truck Unload
- Dead Stack Truck Unload
- Loading docks
- ASRS crane aisles
- Pallet positions
- Mobile robots
- Case positions
- Items per tote

- Mixed Case Palletizing
- Dead Stack Truck Load
- Break Pack “Each Pick”
Picking individual items

![Warehouse Split Case Labor Hours by Job Function](image)

Source: Picking Palooza: How to Select a Case Picking System. Material Handling and Logistics Conference (sponsored by Dematic). 2013
Re-imagining the supply chain

- **Transforming urban delivery**
  - Small footprint, low operating and transport costs
  - Close to customer
  - Fast, flexible delivery
Building winning, talented teams

2013
Edison Award: Productivity

2015
Manufacturing Leadership Award: Supply Chain