

Control of Complex integrated Automated Systems

Emerging Technologies and Case Experiences

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**“goods-to-operator”
order
distribution system**

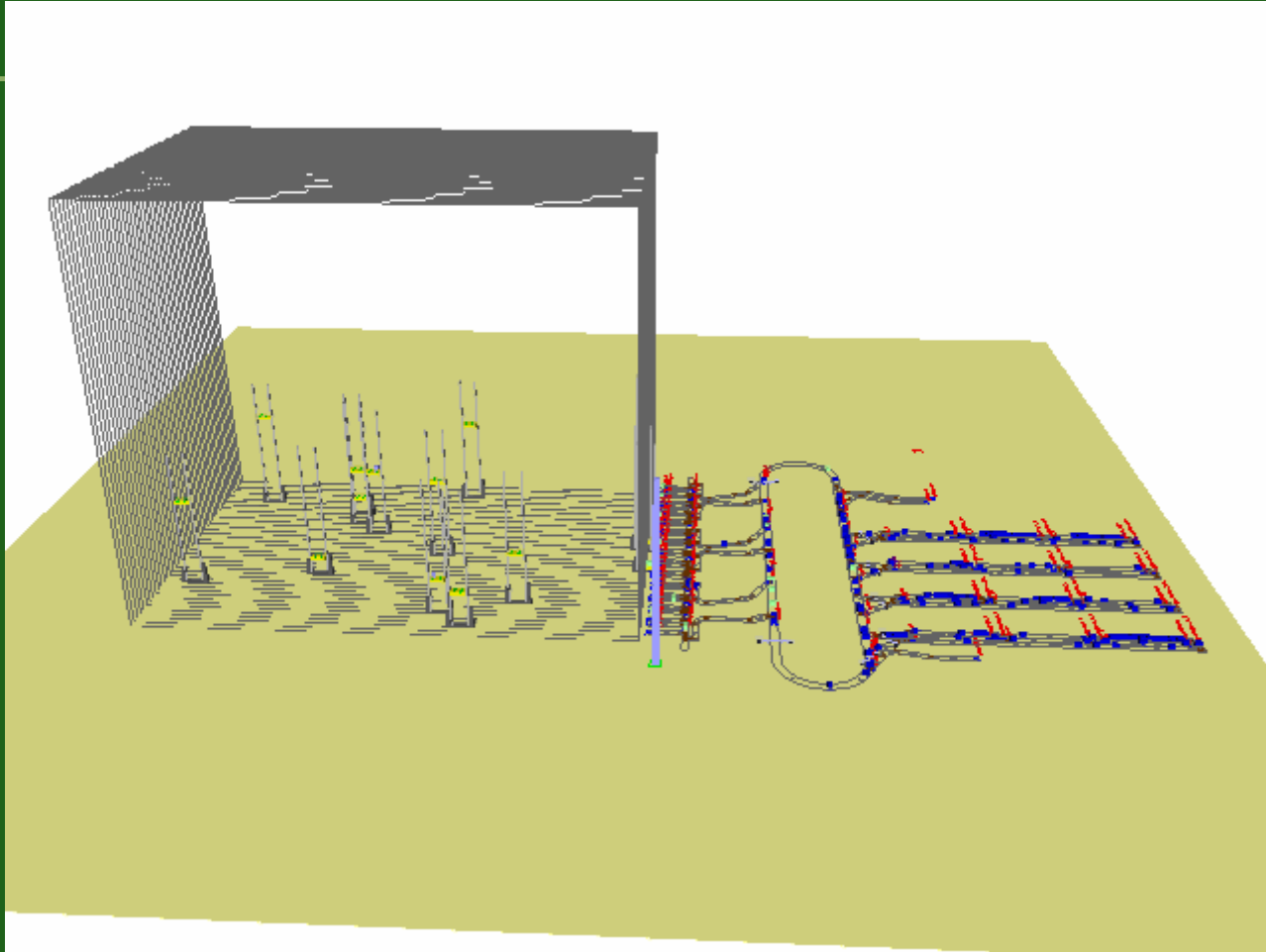


**Rigid integrated controls in
a complex automated
system**



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Animation of Vanderlande Industries (the Netherlands) Order Distribution System



Challenge

Could a complex, integrated, and automated system be made:

More responsive

Less error-prone

Cost-effective

Easier to install and maintain

for high product mix and low volume environments?



Strategy

Keep the automation

and

Change the control architecture

Reduce the layers in the hierarchy
Increase the functionality within a layer
Allocate functions to improve performance



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Topics:

- **trends in control system development for complex integrated systems**
 - * **holonic concepts**
 - * **biological ties**
 - * **agent-based systems**
- **case experience with Vanderlande Industries of The Netherlands**



Holonic Concepts

“The Ghost in the Machine”

Arthur Koestler, 1967

Holonic Concepts

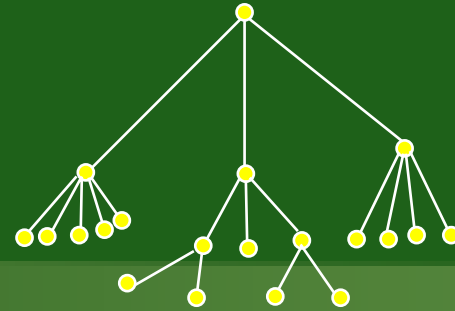
“The Ghost in the Machine” - Arthur Koestler, 1967

“The organism in its structural aspect is not an (simple) aggregation of elementary parts, and in its functional aspects not a chain (or collection) of elementary units of behavior.”

“The organism is to be regarded as a multi-levelled hierarchy of semi-autonomous sub-wholes, branching into sub-wholes of a lower order, and so on.”

“The sub-wholes on any level of the hierarchy are referred to as *Holons*.”

Koestler's Holons



“Hierarchies, as depicted in this tree structure, are found in the most varied fields: genealogy, classifications of animals and plants, social/governmental/industrial organizations, ...”

“When a physiologist looks at any organ *from ‘above’*, from the apex of the hierarchy, (s)he sees it as a dependent part. When viewed *from below*, from the level of its constituents, (s)he sees a whole of remarkable self-sufficiency.”

Koestler's Holons

“Every *Holon* has the dual tendency to preserve and assert its individuality as a quasi-autonomous whole; and to function as an integrated part of a larger whole.”

“Functional *Holons* are governed by fixed sets of rules and display more or less flexible strategies. The rules determine the holon's invariant properties, the strategic selection from among the permissible choices is guided by the contingencies of the environment.”

Biological Relationships

**“Biology’s Big Bang”
Bridgeman**

6/14/07, The Economist



Biological Relationships

“Biology’s Big Bang” - Bridgeman, 6/14/07, The Economist

Animals, be they worms, flies or people, all seem to have the same number of genes for proteins but the animals are vastly different in complexity

- * Traditional genes are not as important in explaining this complexity nor its living operations
- * The answer to the puzzle seems to be the RNA, the organism’s cell operating system, which gets bigger with each advance in complexity
- * RNA not only runs the cell in question but also links up with those of other cells when the creature is developing

Biological Relationships

“Biology’s Big Bang” - Bridgeman, 6/14/07, The Economist

The emerging biological picture, therefore, is

one of “hard-wired” simple organisms which *mostly use RNA for fetching and carrying*, i. e. a humble carrier of messages and a fetcher of building materials,

and “soft-wired” complex organisms that *employ RNA in a management capacity*, with a vast diversity and complex roles in the cell.



Intelligent Agents

- **Intelligent agents**
 - Representing entities and resources
 - Functioning cooperatively
 - Accomplishing individual, cell-wide and system-wide goals
 - The RNA of complex automated systems

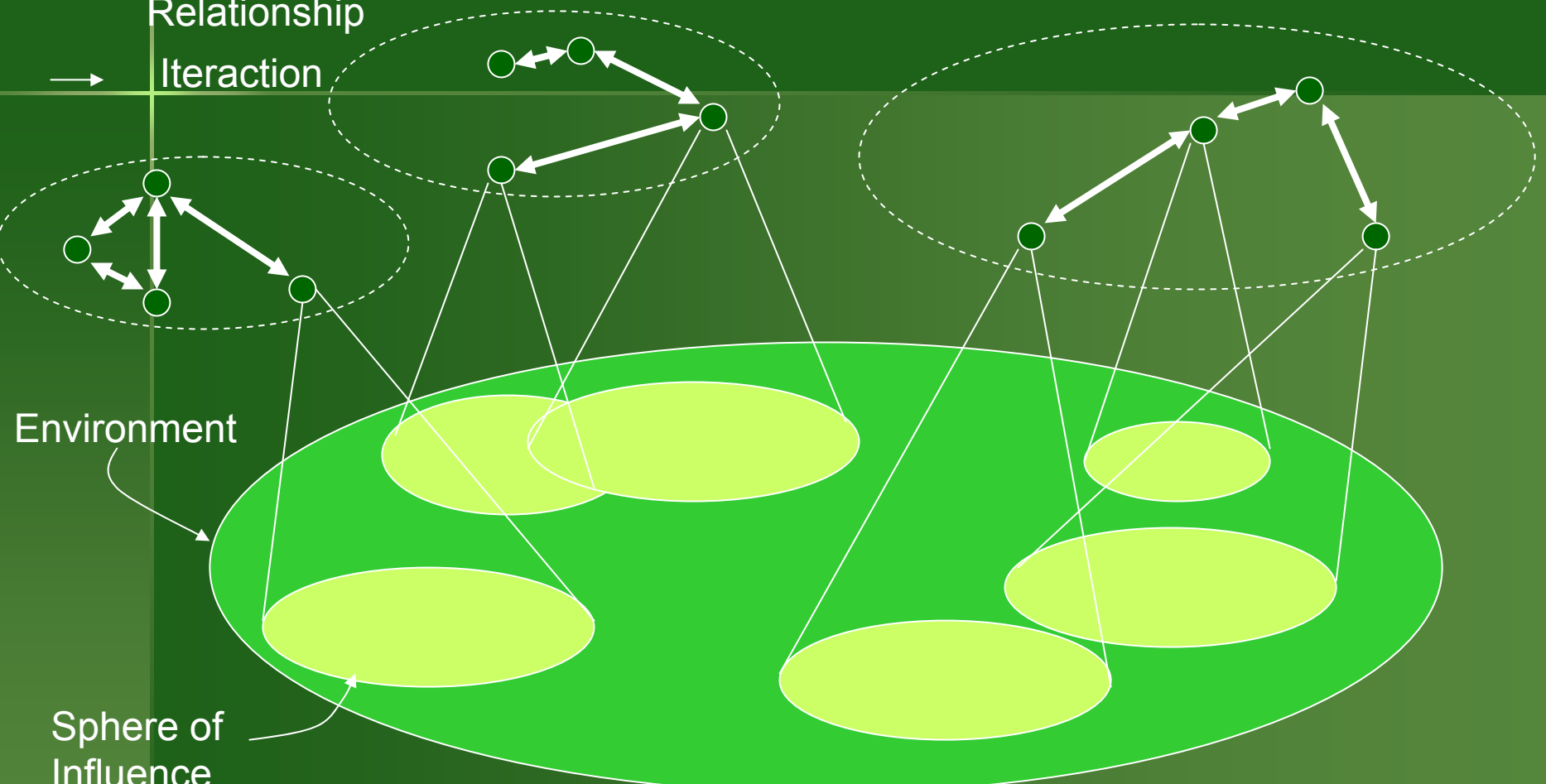
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STRUCTURE OF MULTI-AGENT SYSTEMS

○ Agent

○ Organizational Relationship

→ Iteration



From M. Wooldridge, An Introduction to MultiAgent Systems, p. 106, 2001, Wiley and Sons



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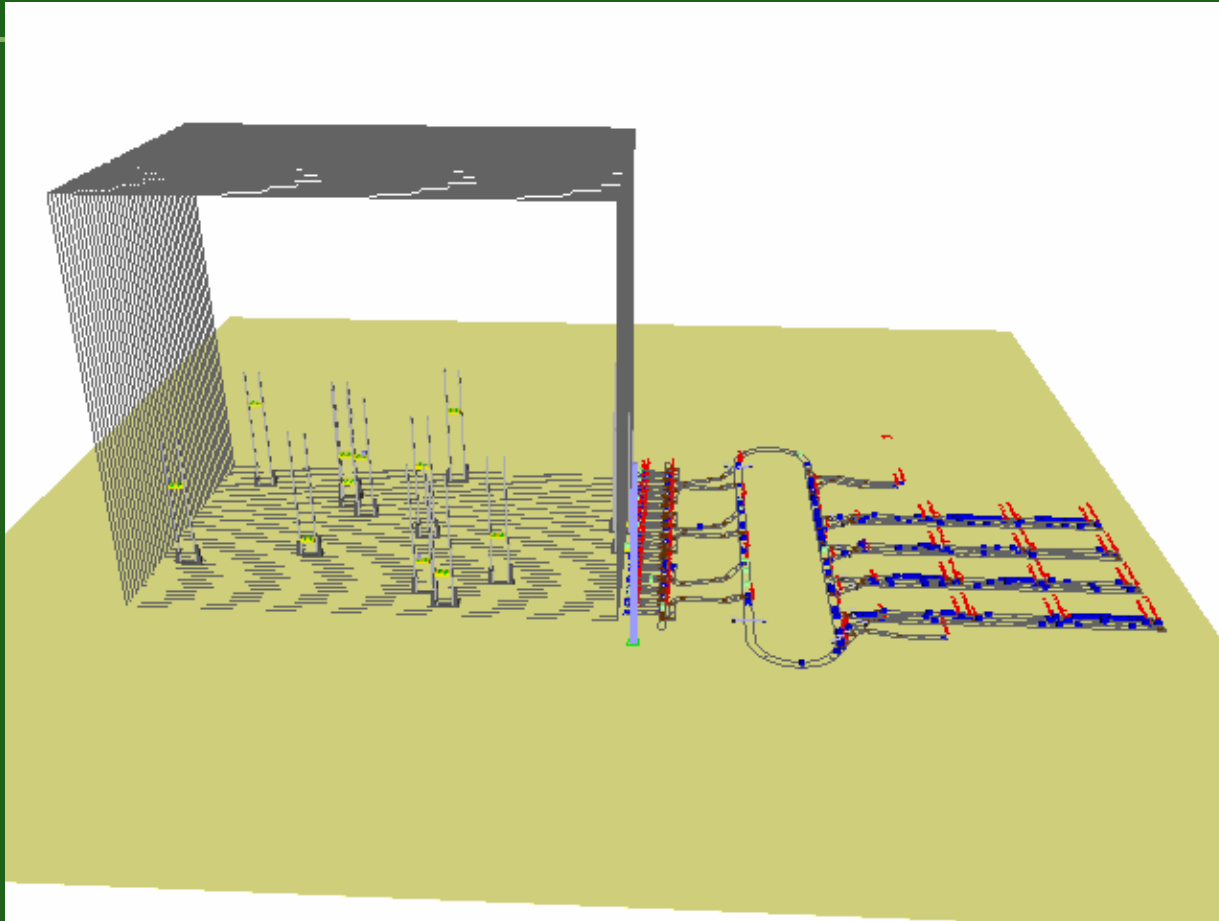
Research Work with “goods-to-operator” *order* *distribution system*



Re-building the
control system using
agent-based approaches

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Animation of Vanderlande Industries' (The Netherlands) Order Distribution System

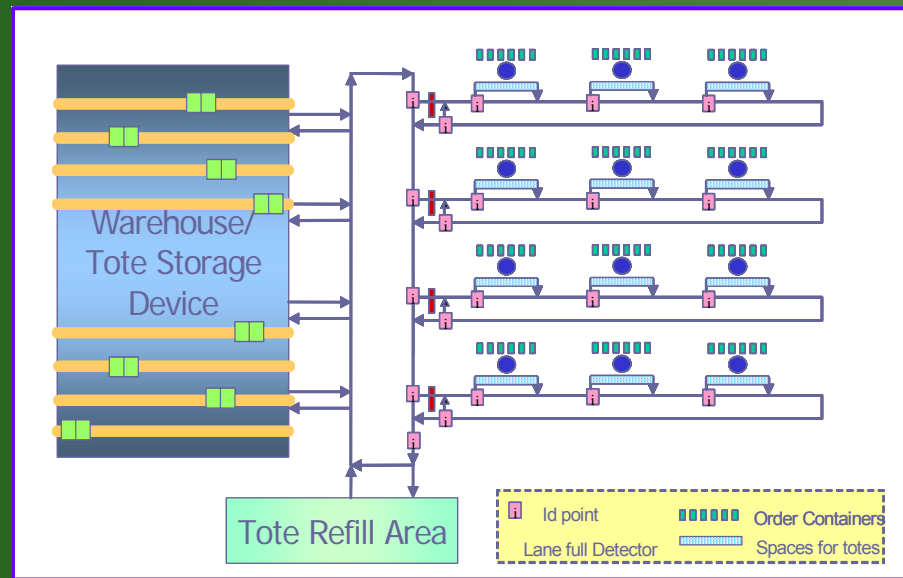


Research Approach Used

- Elements re-built with agent-based technologies
 - SKU Management
 - SKU Assignment Task
 - SKU Routing
 - Crane Management
 - Crane Retrieval Selection
 - Crane Putaway Selection
- Use of the Contract Net Protocol and agent-based concepts to guide agent behavior
- Increase number of decision points to enhance system agility
- Test using order set of 1,000 orders with average order lines per order in excess of 14 and accounting for 44,027 units
- Simulation to assess performance under stable and disturbed conditions

Functions in Vanderlande's ODS

- Order Assignment (OA) → Order
- SKU Retrieval (SRe) } SKU
- SKU Routing (SRo) } SKU
- Crane Retrieval Selection (CRS) } Crane
- Crane Putaway Selection (CPS) } Crane



SKU Management

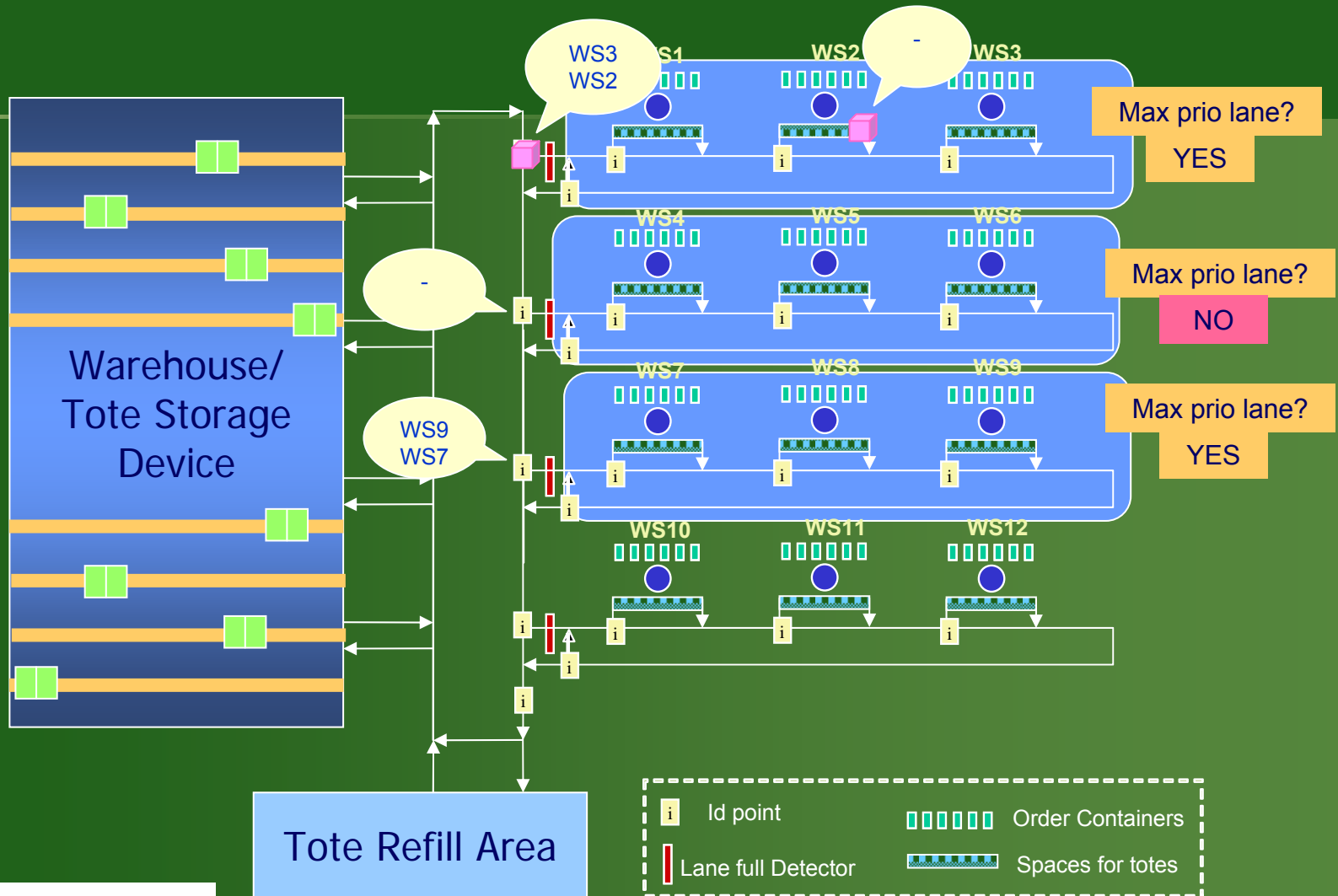
SKU Routing (SRo)
SKU Retrieval (SRe)

Existing SKU Routing (SRo)

1. Create Destination List (DL)
 - DL is composed of one or more workstations (WS)
 - DL is fixed ahead of time for each product tote
 - Determine the lane, then determine WS in the lane to be added to the DL – according to demand priority
2. Route tote to a WS in DL
 - The first WS to which tote is routed is determined by the proximity of the WS to the tote's location → tote can be routed to a low priority WS → increase system tardiness

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Existing SRO



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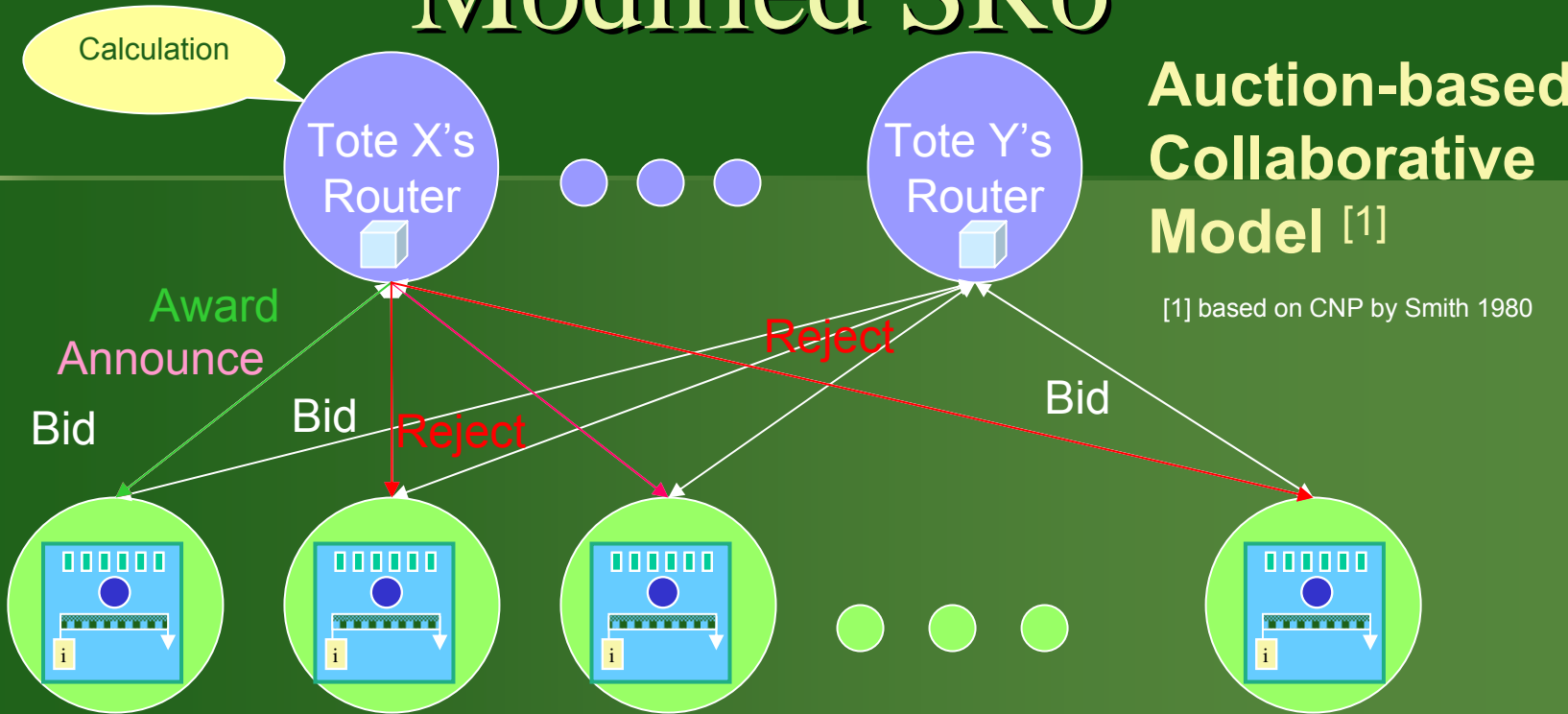


Modified SKU Routing (SRo)

- SRo selects only the best WS as the destination for the tote
- Increase the number of decision-making locations for routing and rerouting capability ~ **more real-time decision making**
- Utilize auction-based collaborative model among *tote routers & workstations* → **Contract Net Protocol (CNP)**^[1]

[1] Smith 1980

Modified SRO



[1] based on CNP by Smith 1980

Announce Info → SKU #, Quantity in Tote, Location

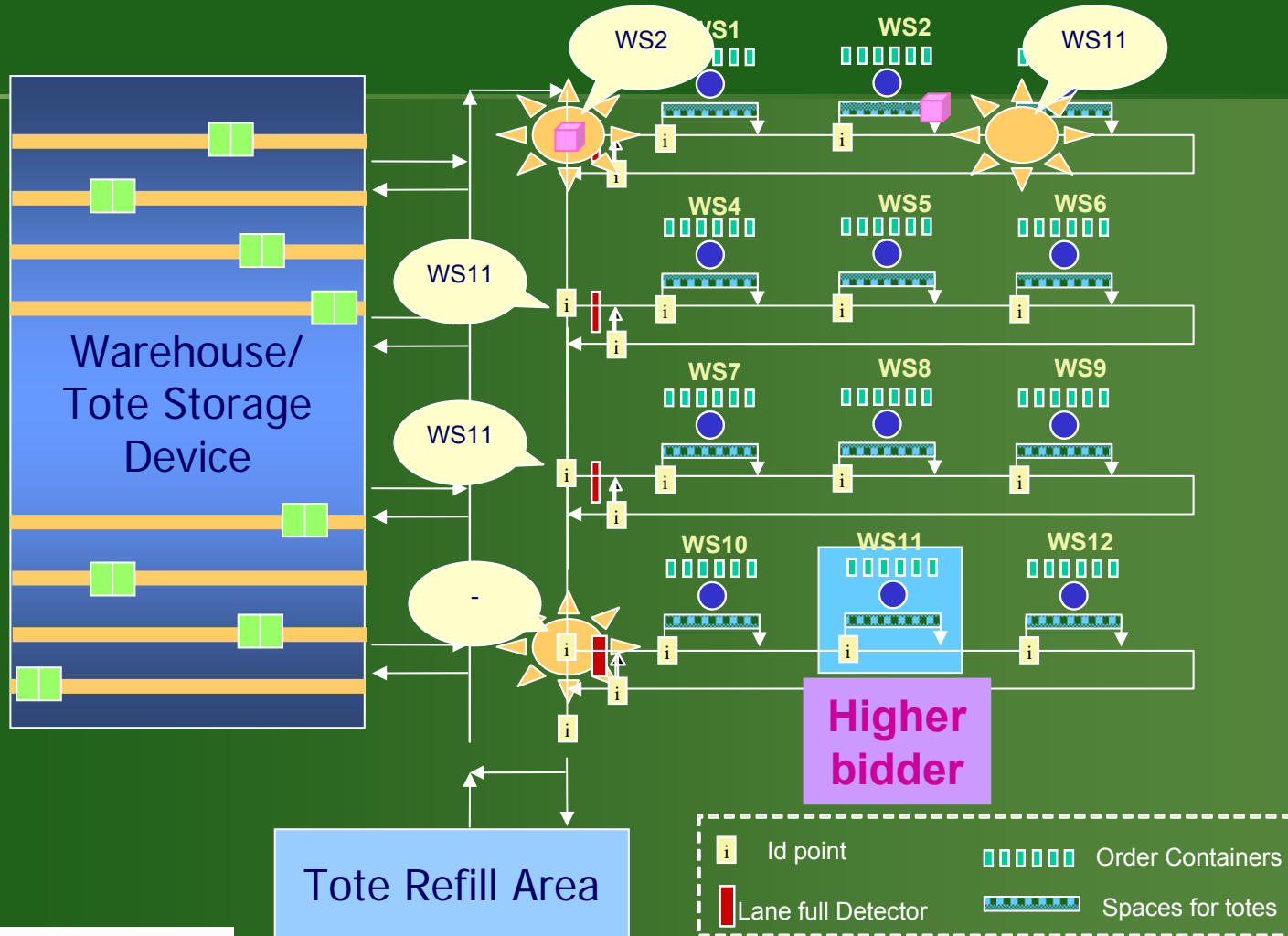
Bid = Function (Priority, Distance, Tote Count)

Bid = Priority – Distance - j * Tote Count

where j = 1 if Tote Count > 5,

j = 0 otherwise

Modified SRO



SKU Retrieval (SRe)

1. Assess the system's demand and supply → list net demand SKUs and sort list according to priority
2. Select next SKU from the list, look at WS space availability
 - *If at least one WS has space available, select this SKU for retrieval*
 - *If no WS has space available, no retrieval task is generated*

If Tote Count_{WS} ≥ WS Tote Count limit → WS has no space
If Tote Count_{WS} < WS Tote Count limit → WS has space

$$\text{Tote Count}_{\text{WS}} = \# \text{ totes}_{\text{WS}} + \# \text{ totes en-route}_{\text{WS}}$$

Modified SRe

- Use *integer-based* tote count for calculating workstation space availability
- Recalculate the SKU list every 2 min
 - Existing SRe:
 - refresh SKU list every 15 min
 - when the priority of selected SKU < initial max priority of the list
- Add capability to respond to CRS request

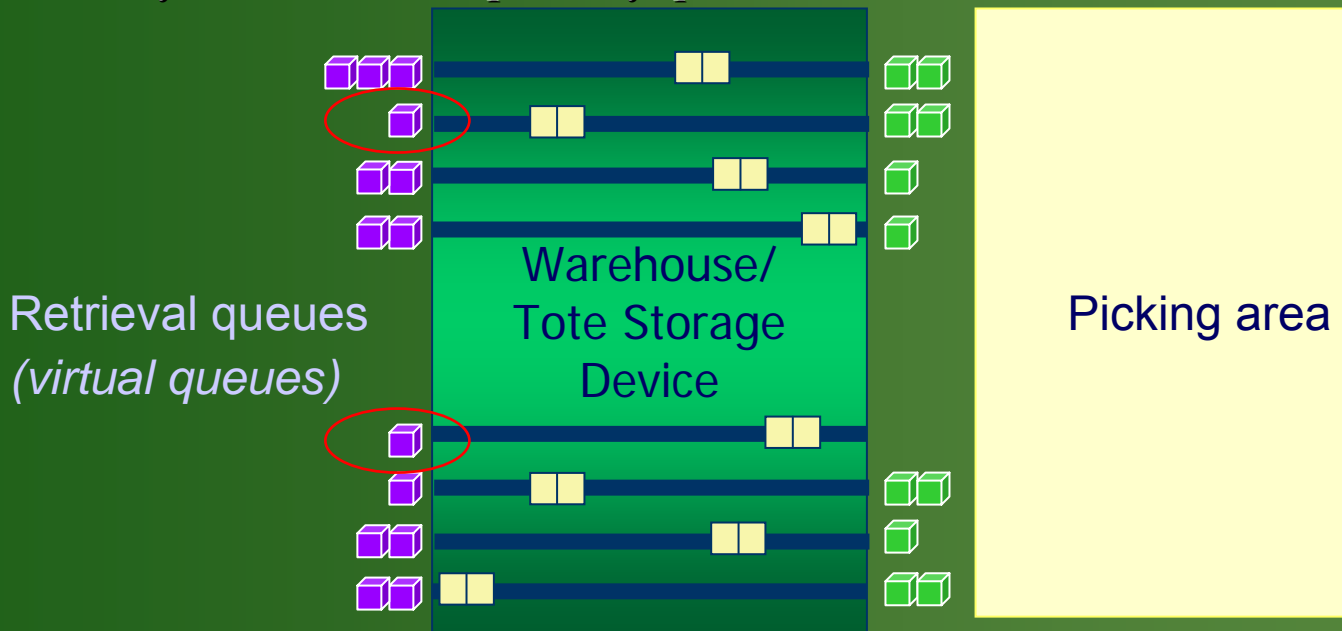
Crane Management

Crane Retrieval Selection (CRS)
Crane Putaway Selection (CPS)



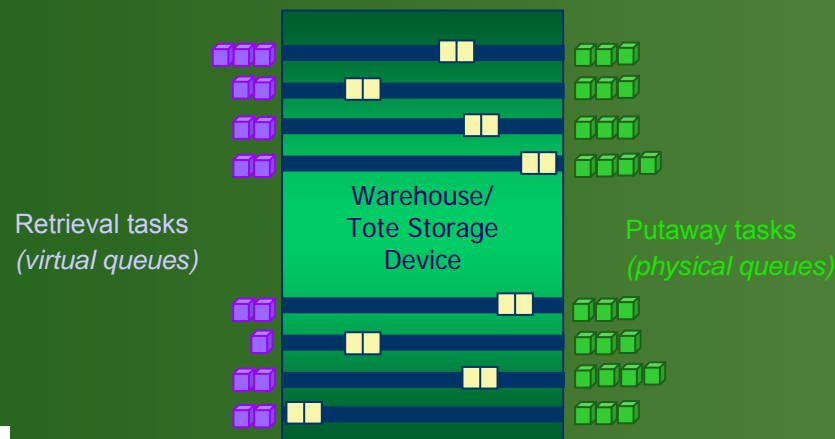
Existing Crane Logic

- Employs a centralized approach
- Top level scheduler creates schedules for cranes using fixed dispatching rules
 - Retrieval task – Shortest retrieval queue
 - Putaway task – Shortest putaway queue



Modified Crane Logic

- Apply auction-based collaborative model
 - CRS: $Bid_{\text{retrieval}} = \text{fn}(\text{retrieval queue, \#active retrieval totes})$
 - CPS: $Bid_{\text{putaway}} = \text{fn}(\text{putaway queue})$
- Encourage collaboration among CRS and CPS
 - **Case1** Balanced tasks – maximize overall crane utilization
 - Utilize both tote positions on each crane
 - **Case2** High # of putaway tasks – maximize putaway utilization
 - CRS requests SRe to temporarily stop generating retrieval tasks



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Research Results

<u>Static Conditions</u>	Existing	Re-Built	Improve.
Total time to complete order stream	6.36 hr	4.67 hr	26%
Avg. order processing time	103.73 min	78.55 min	24%
Std. dev. of order processing time	50.7 min	33.89 min	33%
Avg. operator performance (lines/hr)	195.50	265.39	36%
Avg. Crane utilization	62.35%	85.82%	38%

Disruptions

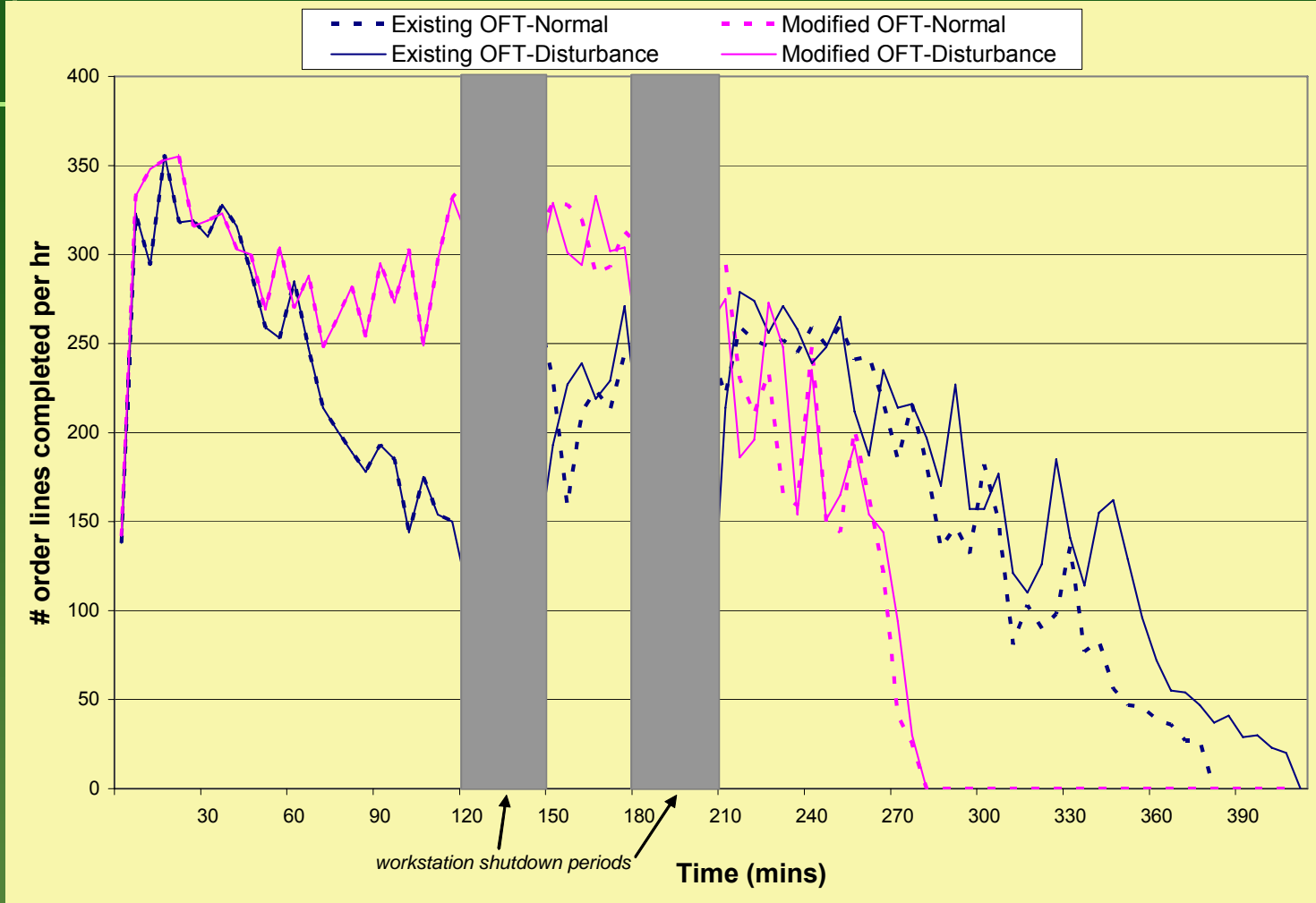
Total time to complete order stream	6.84 hr	4.72 hr	22%
Avg. order processing time	113.00 min	79.92 min	29%
Std. dev. of order processing time	55.98 min	34.97 min	38%
Avg. operator performance (lines/hr)	181.37	265.2	46%
Avg. Crane utilization	58.36%	86.45%	48%



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Graph of Results

Operator Performance



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Observations

- Under normal conditions (i.e. no disturbances) the retrofit attention to the crane function would be the most cost effective approach.
- With disturbances present, the SKU function group (including routing) plays a much more important role. This suggests that both crane and SKU modifications are desirable in a retro-fit.

Summary of Findings

- Agent-based / holonic control
 - Improve system throughput performance
 - Improve operator and crane utilization
 - Increase system fault tolerance

- Numerical results
 - Normal condition:

Performance Measure	%Improvement
Total time to complete order stream	22.3 - 27.8%
Average order processing time	22.6 - 24.3%
Std. deviation of order processing time	28.9 - 33.1%
Average operator performance	28.9 - 33.1%
Average crane utilization	31.8 - 40.6%

- Disturbance condition:

Performance Measure	%Improvement
Total time to complete order stream	24.3 - 31.0%
Average order processing time	26.0 - 29.3%
Std. deviation of order processing time	31.7 - 37.5%
Average operator performance	31.7 - 37.5%
Average crane utilization	34.2 - 48.1%

Conclusions

- Under normal conditions (i.e. no disturbances) the holonic/agent-based control systems appear to perform about the same or a little better than traditional control system architectures
- With interruptions present, the holonic/agent-based systems appear to function significantly better than traditional approaches

Conclusions cont'd.

- Both retro-fit and original design instances for the holonic/agent-based control systems offer system performance improvements
- Work with universities can provide benefits in research and development as well in applications to practice



Original Challenge

Could a complex, integrated, and automated system be made:

- More responsive ☺ ☺ ☺ ☺
- Less error-prone ☺ ☺ ☺ ☺
- Cost-effective ☺ ☺ yet to be proved
- Easier to install ☺ ☺ yet to be proved
and maintain

for high product mix and low volume environments?



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