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Business Intelligence Design for Live Piloting of Order Fulfillment Centers[†]

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Abstract. Order fulfillment centers focus on fast paced timely preparation and outbound shipment of customer orders from a large mix of temporarily stored inbound products acquired to satisfy these orders. In order to be both price and service competitive, such fulfillers thrive on real-time synchronization and bee-hive efficiency in highly turbulent demand and supply. Originally conceived for simpler slower pace warehouses and distribution centers, warehouse management systems (WMS) have been transplanted for use in fulfillers. They help fulfillers survive the complexity, yet at the cost of lower productivity and service levels. This paper proposes enhancing WMS with Business Intelligence to create a Fulfiller Piloting System (FPS). The aim is to enable smart live piloting of fulfillers, exploiting the real-time feed of information from both sides of the fulfiller's demand and supply network, as well as from its internal operations. A FPS drives for dynamic distributed synchronization of operations and optimization of decisions by a combination of human and virtual agents, with the objective of higher overall productivity and service.

Keywords. Order fulfillment centers, business intelligence, live piloting system, warehouse management system, distribution operations, multi-agent systems, agent oriented simulation, planning and control.

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1. Introduction

Order fulfillment centers have become highly strategic hubs in the demand and supply networks of businesses combining high throughput and large product mix and serving a large number of customers. Their widespread growth is demonstrated by the Order Fulfillment Council of the Material Handling Industry of America being one of the trade association's most vibrant constituencies.

Whereas the warehouse was traditionally associated with slow pace simpler low-value-added operations and low turnover rates, the fulfiller (Montreuil, 2006) is characterized by fast paced more complex and higher value added operations with high turnovers. This has lead to significant technological innovations having gained momentum in such centers. Examples include pick-to-voice and pick-to-light technologies, A-frames and automated sorting systems.

Being driven by customer orders, fulfillers face head on the market turbulence, with its concurrent high velocity, variability and uncertainty. Fulfillers often also directly face supply turbulence. Contrarily to distribution centers which typically buffer against supply turbulence with large inventories, fulfillers ultimately aim for no stock, with a continuous flow of products cross docking the facility. Most fulfillers have stocks as a time buffer, yet with short durations-of-stay counted in terms of hours or days. This makes fulfillers quite a challenge to manage for sustained price and service competition. Their thriving stems from real-time synchronization and bee-hive efficiency, which is hard to achieve.

Figure 1 provides an example of order fulfillment center, here termed the BloomNet center. It is a flower export hub in the Netherlands. BloomNet gets orders for various flowers on the phone and on Internet and promises to deliver them within hours to locations ranging from anywhere in Europe to most cities in the world. BloomNet buys its flowers at the Aalsmeer auction. It competes every round for getting its selections at good prices.

The business runs as such a fast pace that it often sells flowers which it has not yet bought and will have to get to another continent within 24 hours. In fact at 4h00 AM, it knows in average less than 30% of its to-be-shipped orders, and by 11h00 AM it knows about 80%. It regularly speculates on forecasted sales by buying some flowers for which it has no client order yet. Rarely do flowers spend more than a day or two in the center. Most spend only a few hours, some just a few minutes.

Flowers arrive in the center from the auction and grower sites and are staged until ready to be either directly sent to sorting and shipping, or stored temporarily in the cooled storage area. Some orders require value added services such as having flowers packed in boxes, repacked in foils, or yet even assembled into bouquets. Many flowers are shipped by trucks all the way to their client, others have to be transferred to airplanes. When deemed appropriate, stored flowers are picked up and put onto a conveyor system leading them to the packing or repacking cells, the cooling room for airplane orders, the bouquet department, or directly to their assigned sorting exit lanes. On these lanes, they are put on customer assigned trolleys. Once completed, trolleys are moved to the shipping buffer zone. From this buffer, they are then loaded into the appropriate truck responsible for the route serving their customer. A typical day involves many tens of employees working to ship to hundreds of distinct clients and several thousand flower buckets.

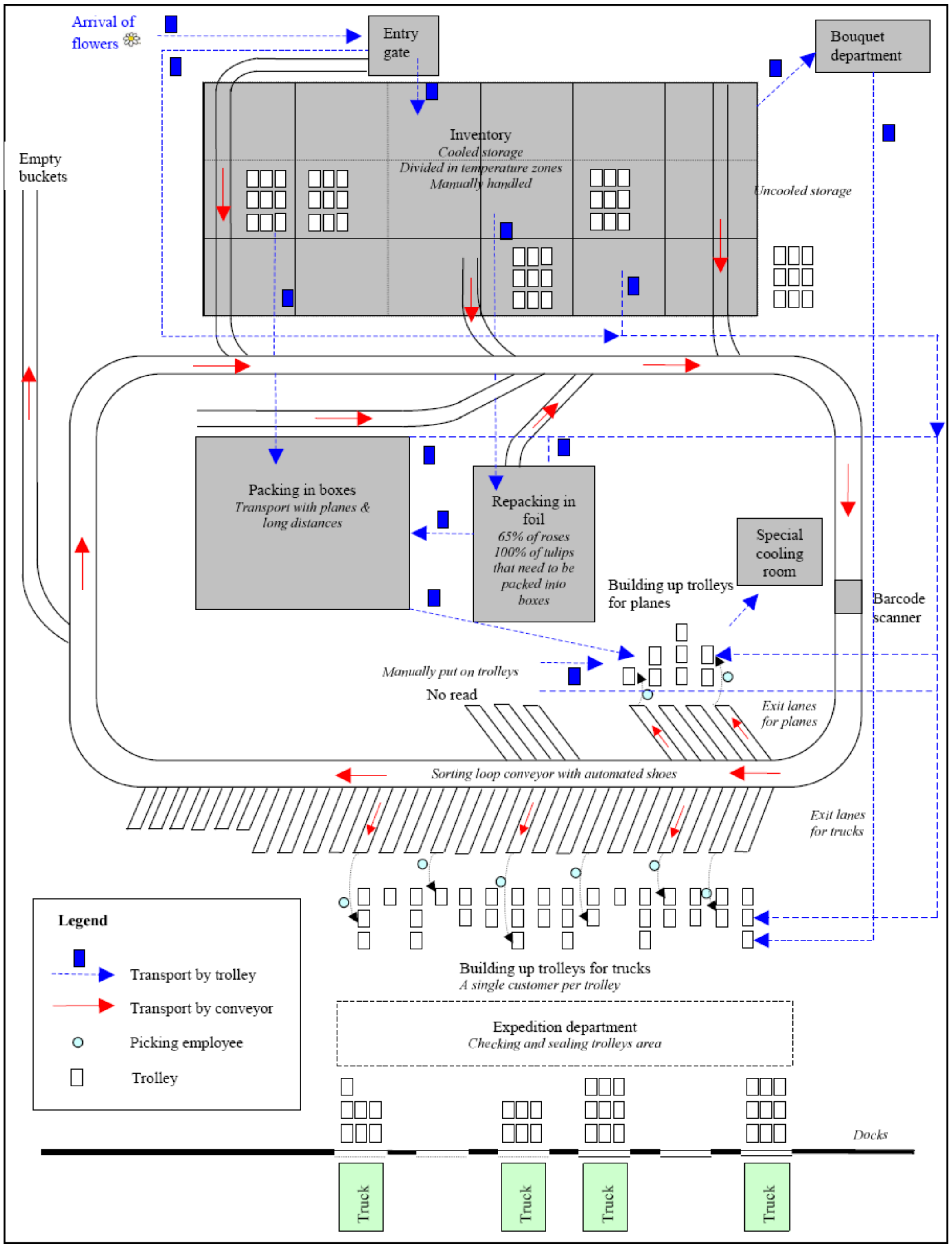

Figure 1: BloomNet order fulfillment center, with its main activities and flower flows

Most fulfillers are currently managed through the combination of a core warehouse management system connected to an enterprise management system, simple control rules embedded in automated systems, local pragmatic decision making by distributed operators and supervisors, as well as overriding exception handling and planning by managers. This arrangement depends heavily on the core WMS. Such systems have originally been conceived for simpler slower pace warehouses and distribution centers. They have been transplanted for helping fulfillers survive the sheer complexity of their operations, yet this has generally been achieved at the cost of lower productivity and service levels.

This paper proposes enhancing WMS with Business Intelligence (BI) to create a Fulfiller Piloting System (FPS). The aim is to enable smart live piloting of fulfillers, exploiting the real-time feed of information from both sides of the fulfiller's demand and supply network, as well as from its internal operations. A FPS drives for dynamic distributed synchronization of operations and optimization of decisions by a combination of human and virtual agents, with the objective of higher overall productivity and service.

The remainder of this paper is structured as follows. Section two reviews literature on warehouse management systems and stresses their limitations for supporting operations of order fulfillment centers. Section three does the same for business intelligence systems. The fourth section reviews previous research on integrating business intelligence systems and warehouse management systems. Section five introduces and describes the proposed fulfiller piloting system and its functionalities. Finally, Section six presents concluding remarks.

2. Warehouse Management Systems

According to Faber et al. (2002), a warehouse management system (WMS) is a short-term planning and shop-floor control system for warehousing, cross docking, and sometimes transportation activities.

Piasecki (2005) emphasizes that a WMS is designed to maximize warehouse throughput and customer service by controlling movements of inventory into, around and out of the distribution center. Key capabilities of such systems include movement control, allowance for controlling multiple storage locations per item, and product retrieval control with or without optimized picking. In addition, typical WMS solutions offer flexibility in the description of the distribution center layout. Each location within the center can be specified in a 3D coordinate system. Optimized picking paths can be specified to guide the workforce on the floor through technologies such as pick-to-voice and pick-to-light.

The detailed setup and processing within a WMS can vary significantly from one software vendor to another. Yet the basic logic generally uses a combination of item, location, quantity, unit of measure, and order information to determine where to stock, where to pick, and in what sequence to perform these operations, (Piasecki, 2005).

Faber et al. (2002) identify three WMS functionality clusters: warehouse management, warehouse execution control and inter-warehouse management. Piasecki (2005) describes the main functionalities of WMS as follows.

- Wave picking/Batch picking/Zone picking: *support for various picking methods varies from one system to another*.
- Task interleaving: *functionality that mixes dissimilar tasks such as picking and put away to obtain maximum productivity*.
- Automated Data Collection (ADC): *usually in the form of radio-frequency (RF) portable terminals with barcode scanners*.
- Integration with Automated Material Handling Equipments, *such as carousels or sortation systems*.
- Integration with cross docking activities.
- Slotting: *activities associated with optimizing product placement in pick locations in a warehouse*.
- Yard Management: *schedule and manage docks for shipment arrivals and departures*.
- Labor tracking/Capacity planning: *some WMS systems provide functionality related to labor reporting and capacity planning*.
- WMS in combination with something else: *financial, light manufacturing, transportation management, purchasing and sales order management systems are often added to WMS*.

Since a distribution center is a node in the flow of products serving or steered by other business functions, like purchase and sales, a WMS has to communicate with other management information systems, about order acceptance, product control, finance, etc. Furthermore, a WMS has to communicate with technical systems to control material handling within a warehouse (Faber *et al*., 2002).

Table 1 shows the functionalities that several WMS suppliers offer in their WMS packages today. It shows that almost all the WMS packages offered by the studied WMS suppliers include the standard warehouse management system functionalities indicated above. Furthermore, most of the WMS support the management of value added services and the use of automatic data collection, for example by barcode scanners, voice picking, and RF scanning.

The environmental pressure on distribution centers for higher performance leads to the implementation of WMS to acquire timely and accurate information about products, resources, and processes that are essential to realize a planning and control structure that effectively and efficiently achieves high operational performance (Faber *et al*., 2002).

The evolution of WMS is very similar to that of many other software solutions. Initially a system to control movement and storage of materials within a warehouse, the role of WMS is expanding to including light manufacturing, transportation management, order management, and complete accounting systems. Like the other software solutions, the true quantitative decision support system came late in the evolution of WMS. The expansion of the overlap in functionality between WMS and other systems focusing on Enterprise Resource Planning, Distribution Requirements Planning, Transportation Management, Supply Chain Planning, Advanced Planning and Scheduling, and Manufacturing Execution will only increase the level of confusion among companies looking for software solutions for their operations.

Table 1: Functionalities offered by a sample of WMS suppliers

Company	**WMS**	**TMS**	**YM**	**LM**	**OMS**	**SCIV/ SCEM**	**VAS**	**AMHE**	**ADC**	**Other**
Fujitsu Software	x	x	x	x			x	x		Warehouse Intelligence Solution
HighJump Software	x	x	x	x	X	x	x	x	x	
Irista	X	x	x		X	x	x		x	Inventory Management
Manhattan Associates	X	x	x	x	X		X		x	Collaboration, Trading Partner Management, Reverse Logistics Management
MARC Global Systems	X	x	x	x		x	X	x	x	International Trade Logistics
Oracle Software	X	x	x		X		X	x	x	
Red Prairie	X	x	x	x	X	x	X		x	Optimization
SAS Software	X					x				
SSA Global	X	x	x	x	X		X	x	x	Consultation
Swisslog Software	X	x	x			x	X		x	

Key to acronyms
WMS - warehouse management system
TMS - transportation management system
YM - yard management
LM - labor management
OMS - order management system
SCIV/SCEM - supply chain inventory visibility/supply chain event management
VAS - value added services
AMHE - automatic material handling equipment
ADC - automatic data collection

Most of the studied scientific papers and professional articles related to WMS are focused on their functionalities, selection and implementation. A few researchers assess that the current WMS are not optimal. Van den Berg (1999) and Van den Berg and Zijm (1999) describe several modules that can be added to improve a WMS. Ashayeri and Kampstra (2003, 2004) argue the need for an Intelligent Logistics Planning and Control system as part of the WMS to closely coordinate the decision-making processes of purchasing, sales, and logistics departments. Van den Berg (2005) mentions that the media attention to voice picking RFID, system integration, connectivity, technology and integration of material handling systems, while a sound decision support system is lacking. He concludes that even specialized WMS still use simple heuristics and that in many cases the warehouse performance would be improved manyfold using optimized planning and control policies. This observation is supported by other authors like Gademan (2001) who suggested that there is a serious demand for full operational control and mid-term planning procedures.

Ashayeri and Kampstra (2003) identify four main management decision areas a warehouse needs to deal with: justification, design, planning, and control. The justification and the strategic design decision-making processes are decisions made at the strategic level and have a long-term impact. Therefore, supporting these decision-making processes is less expected from a WMS. However, the tactical design decisions, the planning decisions, and the control decisions are short-term decisions whose support is more expected from a WMS. *Tactical design decisions* can be warehouse management adjustments (like storage allocation policies), order picking policies, and performance analysis of planning and control policies at operational level. *Planning decisions* generally focus on the selection of the actions and activities (how to conduct the operations) and on the set of rules and policies. Finally, *Control decisions* determine what operational decisions have to be made next. The planning level decides about the set of rules and policies, and the control system is responsible for the execution of these rules and policies. Basically, current WMS are mostly restricted to enabling control decision making.

Current WMS solutions have yielded significant savings to users and helped them develop important competitive capabilities. Yet, distribution centers and order fulfillment centers face increasingly tougher customer demands. There are increased requirements for short response-time, better service and lower prices while the centers are continuously crowded with increasing volume of goods. This translates in a need for increased efficiency, involving better realization and synchronization of logistic activities such as warehousing, handling and transportation. This results in a growing need for more intelligent management systems enabling greater capability to rapidly, reliably and profitably service the customers in highly volatile and competitive environments.

The transformational need is related mostly to operational performance optimization. The topic of logistic optimization in warehouses, distribution centers and order fulfillment centers has been widely studied, resulting in a rich pertinent literature. Yet this literature mostly reports on optimizing a single process and its associated decisions. Very few attempt to take into account the dynamics of all decisions involved in all processes.

According to Ashayeri and Kampstra (2003), the tasks in a distribution center fit into five major steps: (1) managing the on-line order data; (2) dividing the orders into order-picking lists; (3) dispatching human and/or mechanized resources to the picking lists; (4) sorting, packing, loading trolleys or pallets, and shipping; and (5) measuring performance of order-picking processes. In cross-dock centers they add to this list the staging tasks, storing products for a short-term period. They suggest that the order picking, sorting, and shipping processes are the most important logistic activities in a distribution center in volatile environment and should be tackled concurrently through a synchronized planning and control system. They emphasize that order picking has the largest impact on response time and costs. Order picking often leads to between 60% and 70% of the labor costs in distribution centers. There are several ways to pick orders. The most widely used are picking per order, per batch, and per zone. These ways all gain efficiency from optimization of the picking routes. A number of routing methods have been devised to determine the routes. Examples include S-shape or traversal routing, largest gap routing, combined routing, and optimal routing. In a volatile and dynamic environment, one-time optimization of the order picking process is not satisfactory, involved decisions must be continuously updated based on the state of the distribution center, as assessed through an intelligent system.

A field study by Van den Berg (2002) suggests that a warehouse management system (WMS) typically releases the orders in waves. For each wave, the WMS computes which tasks have to be performed to pick the orders and assigns a priority to each task. However, in a time-critical supply chains, the products have to arrive at the dock strictly on time so that the various transport schedules are not delayed. Consequently, the priority of an order should increase as the truck's departure time approaches. However, the wave planning of a WMS does not solve this issue. Therefore, Van den Berg (2002) propose a *dynamic routing* approach. In this routing strategy, the WMS observes the progress in the warehouse in real-time via RF communication. Subsequently, the WMS decides which task an operator has to carry out next by taking both urgency as well as efficiency into consideration: the WMS chooses the most urgent task within the zone which the order picker is found.

When items for multiple orders are picked at the same time, these items need to be *sorted* before being transported to the shipping area. Sorting can take place during or after the order-picking process and can be done manually or by an automated sorting system. Ever more distribution centers use sorting systems to sort the grouped orders that are picked. Ashayeri and Kampstra (2003, 2004) define three main tasks of sorting systems: sorting items for shipment; sorting (returned) items (back) into picking zones; and sorting items for packing. They described several considerations a company has to make before implementing an automated sorting system. In addition, they concluded that, in dynamic distribution centers, besides balancing picking and packing rates, picking and sorting activities have also to be balanced.

Products that are picked from the storage area and ordered by clients come together in the *shipping* area. There the loaded trolleys or pallets for clients are inspected and necessary papers are added. Once the transporter arrives, the trolleys or pallets are loaded in the truck and the truck can deliver the goods to the client. Ashayeri and Kampstra (2003) describe the shipping activities and studied several transportation planning methods. Truck departure times are decided using the transport planning systems of the distribution center and the transporters. Because all the products for a client have to be ready before the departure time, the departure times are due dates for the preceding processes in the distribution center: order picking, packing, and sorting. As such these processes must continuously be synchronized with shipment operations.

Figure 2 illustrates typical aggregate product flows in an order fulfillment center, clearly depicting the multiplicity of flowing channels through the center. It is through the integration, global optimization and real time synchronization of activities such as selling, order promising, purchasing, inbound transport, receiving, inspection, storage, order picking, value added service, shipping and outbound shipping that the competitive edge of fulfillers can be gained. From a management system perspective, this requires levels of visibility, collaboration and especially intelligence beyond the capabilities of current WMS technology.

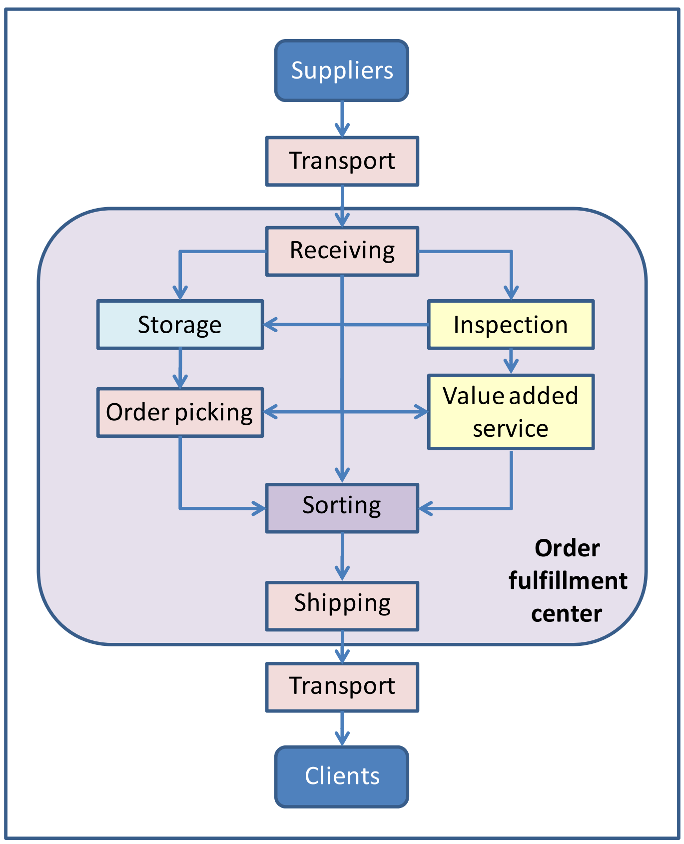

Figure 2: Aggregated product flow in an order fulfillment center

3. Business Intelligence Systems

From an outcome perspective Business Intelligence (BI) can be described as "the knowledge derived from analyzing an organization's information"[1]. BI is all about information and actionable knowledge such that the management is able to make better decisions (Könings and Geurts 2004). From a process and technology perspective BI describes a set of concepts and methods to improve business decision making by using fact-based support systems. It refers to technologies, applications and practices for the collection, integration, analysis, and presentation of business information and also sometimes to the information itself [2].

CSIRO's Business Intelligence Group (http://www.cmis.csiro.au/bi/) describes the BI roles in five stages: (1) d*ata sourcing*, extracting information from multiple sources of data; (2) *data analysis*, creating useful knowledge from collected data; (3) *situation awareness,* filtering out irrelevant information and setting the remaining information in the context of the business and its environment; (4) *risk assessment*, discovering what reasonable decisions might be made at different times and weighing up the current and future risk or benefit of making one decision versus another; and (5) *decision support*: using Decision Support Systems to make good decisions and strategies.

Overall, the essence of BI is to search the right information and to use it in the right Decision Support System (DSS), in order to bring about the right intelligence for the business to make the right decisions. BI tools attempt to derive meaning out of all information that has value. Riggin (2006) states that the tools synthesize the information to show trends in the past, activities in the present, and forecasts where the company might end up if it continues along that trend. He adds that BI tools feature four functions: analysis, visualization, alerts, and creation or modification of reports.

Several firms provide BI solutions to enterprises, offering Business Intelligence Systems (BIS) that support the stages of the BI strategy. BI leading solutions providers currently include Brio, Business Objects, Cognos, IBM, Informatica, Microstrategy and SAS. Software vendors and consulting firms often cooperate to offer customized solutions to customers.

One can distinguish between BI tools designed to support managers to make strategic and tactical decisions, and those that are focused on making operational decisions. Taylor (2005) describes that one of the currently hottest topics of BI is what many call "operational" BI. An enterprise that gets strategic intelligence from its data via a BI system needs a way to push the same degree of intelligence out into its operation and front-line systems. He suggests that even the most advanced BI systems are simply not currently designed to do this. In fact, due to the fact that the roots of most of BI leading solutions are found in supporting financial and market analysis, solutions adapted for the supply chain address mainly financial or marketing issues and lack in providing intelligence pertinent to the management, planning and control of goods and information along the supply chain (Snow 2005 and Trebilcock 2006). While many BI software providers offer solutions that target distribution businesses, these solutions often lack the back-end intelligence that are required throughout the operations of distribution centers and order fulfillment centers.

Almost all companies operate with at least two software applications from different vendors to tackle the functionalities of Supply Chain Management (SCM). Most have at least one Enterprise Resources Planning (ERP) system to do the basic order management, purchasing and accounting functions, and often they use a specific best-of-breed application to provide connections across supply chain processes, such as linking inventory replenishment, transportation management, and warehouse management (Snow, 2005). Many best-of-breed SCM vendors are now adding BI or performance management capabilities to their applications. These BI tools are used to collect, handle, and analyze the available data and to make reports based on the relevant data. However, the BI tools do not currently support distributed decision-making, master data management, visibility of trading partners, and predictive performance management analytics that evaluate supply chain “what if” option planning scenarios (Snow, 2005).

Because of the need for better supply chain intelligence, some software vendors of BI platforms and SCM applications have developed new packages. Business Objects, Cognos, Oracle Software (PeopleSoft EPM), and SAP recently incorporated pre-packaged supply chain-centric analytical applications, and Cognos supports distributed decision-making with business management alerts. However, no BI vendor supports trading partner visibility and detailed supply and demand scenario planning yet (Snow, 2005), let alone distribution center management intelligence.

In their study of Business Intelligence and logistics, Rao and Swarup (2001) concluded that BI tools like data warehousing in combination with transportation management systems, can significantly help a Third Party Logistics (3PL) provider in its objectives of continuously improving its existing services, adding new services, and making its internal organizational functions more effective.

A search of the literature and WMS software solutions shows that BI has been extensively applied in different areas of supply chain management such as Efficient Consumer Response (ECR), Vendor Managed Inventory (VMI), collaborative planning and forecasting relationships (CPFR) in order to decrease uncertainties and for strategic decision-making in both Business To Business (B2B) or Business To Consumer (B2C) contexts. The search also shows that BI is not currently used for planning and control decisions of distribution/logistics companies, especially in distribution and order fulfillment center management. WMS do not include intelligent Decision Support Systems (DSS).

4. Integrating Warehouse Management & Business Intelligence Systems

As reviewed in the previous sections, current Business Intelligence systems and Warehouse Management Systems are restricted to gathering information, assembling real-time data overviews and enacting operational control decision making. Tactical and operational decision-making processes such as short term planning are poorly supported. This section surveys pertinent research on integrating Warehouse Management Systems and Business Intelligence Systems, mostly in the context of distribution centers and warehouses.

The fast dynamics and high uncertainty combine to make it difficult for distribution centers to rely on stable daily planning and scheduling for driving the operations. Change is the constant. Therefore, such centers have to juggle a sense-and-respond double play (Haeckel, 1999). On one side, they can gain from exploiting external Business Intelligence, developing and exploiting knowledge about the needs and behaviors of clients, suppliers and logistic partners. They constantly have to challenge and adapt their estimates about demand, supply arrival times, and so on. On the other side, they can gain from having capabilities for dynamically planning and scheduling their logistic activities, to make real-time on-the-fly decisions provided external and internal BI updates.

Several researchers such as Finnie and Barker (2005), Ito and Mousavi Jahan Abadi (2002) and Kim *et al.* (2002) and several professionals such as Atkinson (2003, 2004) and Maloney (2005) in DC Velocity, propose the implementation of agent-based systems in WMS for more intelligent support of decision-making processes. Furthermore, researchers such as Ashayeri and Kampstra (2003, 2004) and professionals such as Taylor (2005) suggested new smart systems to be added to WMS or BI tools. Below are described that are proposed to be embedded in a LPS.

Intelligent software agents are software packets that act as autonomous decision-making entities, capable of coming up with solutions to problems and acting on them automatically (Atkinson, 2004). Software agents do the same as people: they respond and make decisions as the situation changes. Atkinson (2003) describes that when it comes to complex logistics or warehousing decisions, an intelligent software “agent” may be able to make the call better, faster, or more cost effectively than a human can. Computers are already making decisions about our lives without any human intervention, but this so-called smart software is not yet implemented in significant scale in the logistics and transportation sectors for reasons of money, time, and plain old fear.

Atkinson (2003) mentions that software agents could be very useful in distribution centers. They cut out the delays associated with waiting for a human reaction when a decision has to be made. Agents make decisions in real time. Atkinson (2004) defines two main advantages of using intelligent software agents to help out with dynamic logistics management that responds quickly to changing situations. First, intelligent agents form a collaborative network and act independently. They do not need to operate in lockstep with a master computer. Second, intelligent software agents are able to make autonomous decisions that humans would likely make if only they had the time. Intelligent agents are programmed with parameters that cause them to make what humans would consider good decisions, and they interface with humans on overall plans that spring from those decisions

However, smart software that makes decisions in real time needs better and more accurate data than is commonly available along the supply chain. Therefore, this agent-based software has to be combined with data-collection devices, such as provided in a current WMS. Atkinson (2003) mentions that agents cannot replace humans, but they can support humans: “Any time you have complexity in a business process, you can use agents to support human’s decision-making capabilities. It is all about figuring out what decisions people have to make and asking whether an agent can make that decision better, faster, or in a more cost-effective way”. Maloney (2005) added that computers will make some of the routine decisions, but, because the software cannot know everything, humans will still be handling the exceptions. Finnie and Barker (2005) also mention that agents systems are not limited to acting as advisory systems, retrieving a probable sequence of action to be followed by the human decision-making. They can take charge themselves of some operational decision making, resulting in increasingly automated systems with certain safeguards and limits built in as well as requiring occasional human intervention for difficult cases.

Malone (2005) reports that currently, “intelligence” in WMS is still largely limited to sensors and controls that monitor and deport two key types of information: an item’s location and its status. He emphasizes that the true challenge is the analysis of these data. At present, there are limited technologies commercially available to process the data and filter the important information to make decisions in distribution centers.

From a research perspective, several researchers are exploring agent based systems in distribution centers. Kim *et al.* (2002) use an intelligent agent-based model to study the order picking process in an actual industrial warehouse. Entities (goods or parts) and resources (storage areas) are modeled as intelligent agents. These agents take decisions such as scheduling in a dynamic real-time way. The agents in their model use optimization algorithms, learning, databases, and knowledge bases to make better decisions. Results show that the proposed framework increases the throughput in a distribution center.

Ito and Mousavi Jahan Abadi (2002) implement a of warehouse system framework based on the agent technology, called AWAS (Agent-based model for warehouse system). The system is composed of three subsystems, namely, agent-based communication system, agent-based material handling system, and agent-based inventory planning and control system. These subsystems were designed to cooperate together to facilitate just-in-time exchange of orders and materials. The authors define seven kinds of basic agents: customer, supplier, order, inventory, product, supplier-order, and automatic-guided vehicle (AGV) agents.

AWAS takes care of the ordering process and it arranges the assignment of AGV’s (automated guided vehicle system) and the material flow inside the warehouse. However, the system is designed to achieve an effective information exchange between a warehouse system and its customers and suppliers and not to optimize the processes inside the warehouse. However, the authors do not describe the rules used by the agents to make the decisions.

Taylor (2005) proposes Enterprise Decision Management (EDM), a systematic approach for automating and improving high-volume, operational decisions. The focus of EDM is the evolution from insight to automated action, sometimes called "decision-centric" BI. EDM applies predictive analytics, business rules and other proven technologies to give businesses a much greater degree of control over decisions. Taylor (2005) mentions that the crucial distinction between BI and EDM is that BI helps to *understand* the business; while EDM helps to *execute* business. Furthermore, traditional BI tools are generally used to support executives making strategic and tactical decisions while EDM solutions are most frequently applied to operational decisions. Taylor (2005) does not describe what kind of decisions EDM automates and how EDM can be implemented in a distribution center.

Ashayeri and Kampstra (2003, 2004) assess that distribution centers need Intelligent Logistics Planning and Control (ILPC) embedded in a WMS. Such ILPC must closely coordinate the decision-making processes of purchasing, sales, and logistics departments. They mention various ways in which distribution logistics planning and control can be redesigned. First, information stemming from inside and outside the company has to be shared, which is made possible by today's information technology. Second, decision-making has to be integrated within the operational processes. Third, a company has to avoid overloading sections of a distribution center by proper balancing workload, which may also require close interaction with either suppliers or customers. Fourth, one has to respond better or quicker to capacity requirements. When future bottlenecks are foreseen, one can respond early by shifting or adding capacity.

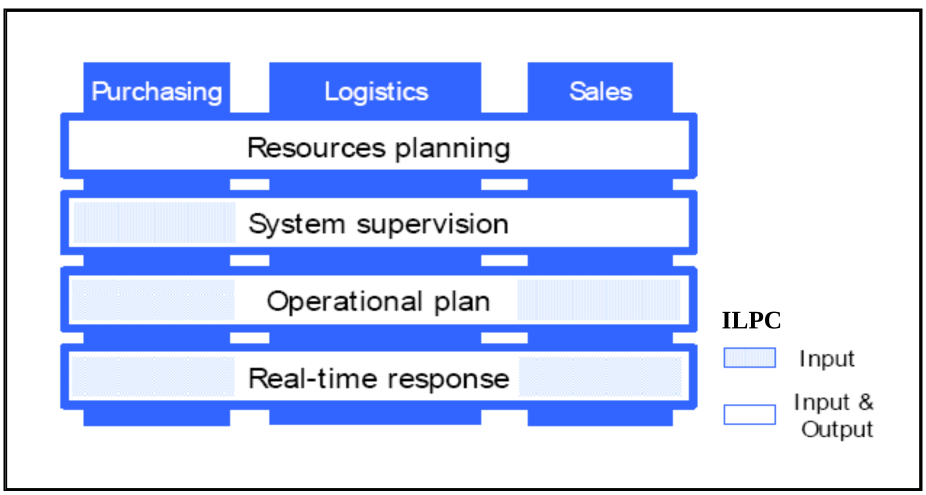

Figure 3: Four decision levels in an Intelligent Logistics Planning and Control system (Ashayeri & Kampstra, 2004)

Figure 3 shows the decision levels and activities in a ILPC system as envisioned by Ashayeri and Kampstra (2004). These layers are in order of decision level: resources planning, system supervision, operational plan, and real-time response. A higher control layer has a higher level of decision-making, but also a lower frequency of decision-making. In the proposed framework, the resource planning is done daily, system supervision hourly, short-term scheduling (operational plan) every 15 minutes, and real-time response occurs immediately as needed. They detail the proposed concept, as instanced for a real-life business case in the cut flower industry. Their ultimate goal is to integrate an ILPC system within the current WMS to coordinate order picking, value added services, and sorting activities with the purchase and sales activities. Table 2 outlines the main functionalities, input sources, and output destination department of the ILPC-system.

Table 2: Functionalities of ILPC proposed by Ashayeri and Kampstra (2003, 2004)

	Control layer	**Frequency**	**Functionalities**	**Planning directives for**
Planning	**Resource Planning**	Daily	1. Sales forecast 2. Purchase forecast 3. Workforce requirements	- Other control layers - Operational manager
	System supervision	Hourly	4. Order fulfillment feasibility 5. Demand feasibility 6. Supply feasibility 7. Shipping feasibility	- Operational manager - Transport planner - Sales department
Control	**Operational plan**	15 minutes	8. Order batching and picking routes 9. Destination assignment to sorter exit lanes 10. Destination assignment to shipping docks 11. Item release to sorter lanes 12. Packer assignment to sorter lanes	- Operational manager - All resources and employees at the work floor
	Real-time response	Real-time	13. Reschedule priority order 14. Item release to sorter exit lane 15. Item release to stock 16. Full unit release to shipping docks 17. Re-assign idle worker 18. Update information	- Idle resources or employees at the work floor

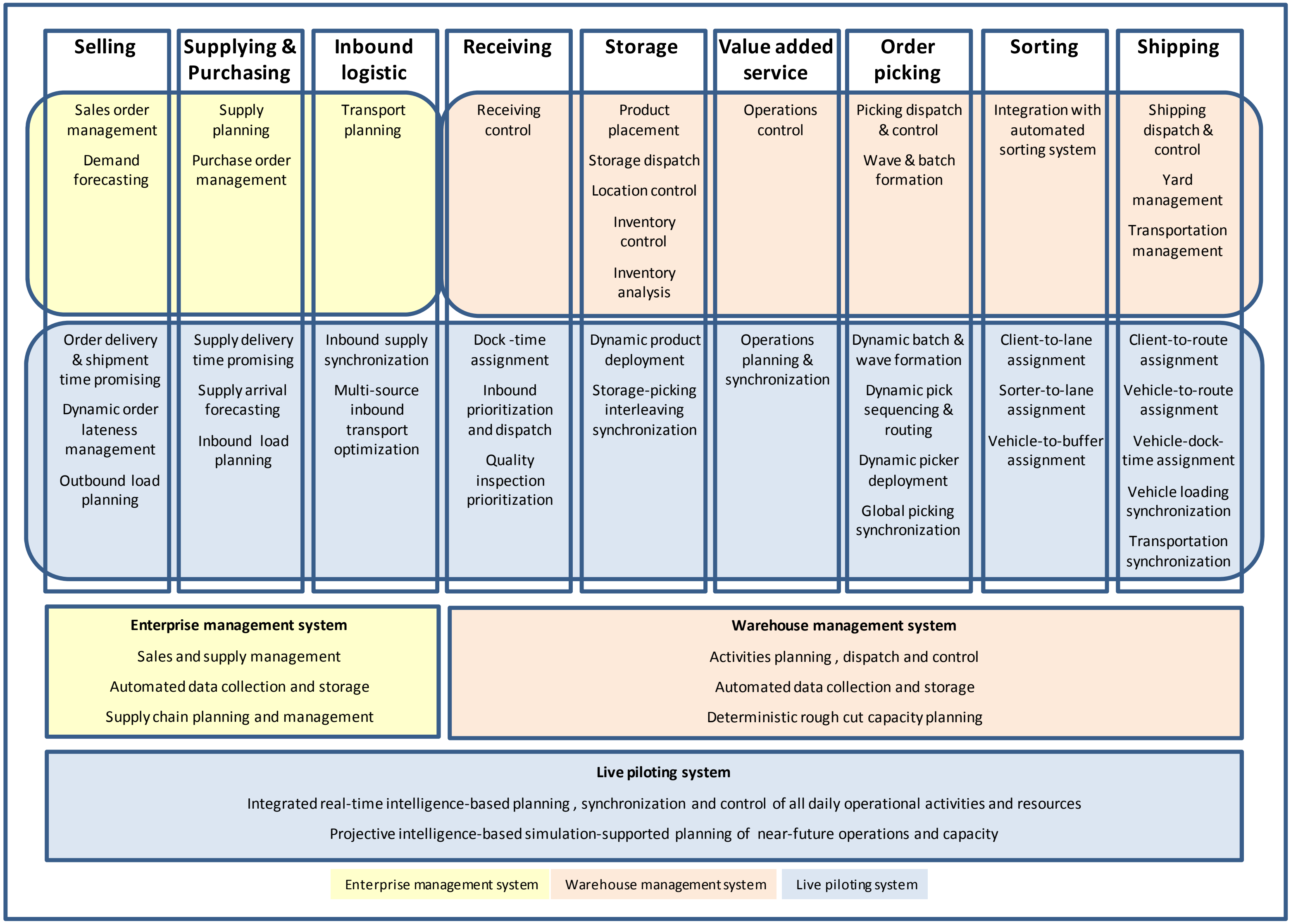

Figure 4: Proposed Fulfiller Piloting System Functionalities

5. Fulfiller Piloting Systems

In the emerging environment, order fulfillment centers (OFC) are expected to thrive in high throughput, high variety, high uncertainty conditions. The competitive pressure for concurrent world class efficiency, productivity, quality and service requires operational excellence from such centers. This section proposes *Fulfiller Piloting Systems* (FPS) as a new breed of system merging the functionalities of warehouse management systems and operational business intelligence system, with the aim of better addressing the challenges of order fulfillment centers. Such systems can be applied in more generic distribution centers contexts, yet may not be necessary for simple operations.

Figure 4 synthesizes the main functionalities of a fulfiller piloting system. The figure is column structured around the main operational activities of an order fulfillment center: selling, supplying and purchasing, inbound logistic, receiving, storage, value added service, order picking, sorting and shipping. Selling has been put first as in the ultimate OFCs, the sales to clients occur prior to the purchase of products from suppliers.

Figure 4 cuts these columns in four layers. The top layer includes the functionalities currently achieved on the left side by enterprise management systems (EMS), such as Enterprise Resource Planning (ERP) systems, and on the right side by Warehouse Management Systems. These are well documented in the previous sections. The second layer from the top includes a large set of live piloting functionalities, each focused on dynamic decision making related to a main activity, in the best interests of the overall center performance. These exploit real-time external and internal intelligence feeds. The third from top layer defines the global functions of each of the two main contemporary types of systems, EMS and WMS, as pertinent to the order fulfillment center. The lowest layer defines the main functions of the live piloting system. Each of the three lower layers is further described hereafter. It should be understood that the provided functionalities are work-in-progress in the evolutionary path from current technology, and that time and experience will prove necessary other functionalities or different groupings of functionalities.

The third level summarizes the main WMS functionalities along three main groups of responsibilities. First are the planning, dispatch and control of activities. As stated previously, in a WMS, planning and dispatch rule setting are not live activities. They are performed ahead of time and mostly become a given, except if a human supervisor r manager manually intervenes. Dispatch is mostly rule based. It generally exploits direct interaction with equipment controllers and interactions with humans through a variety of interaction technologies such as print, display, light or voice. Control tracks products and resources through technologies such as bar coding and RFID.

The second main WMS functionality is automated data collection and storage for legal purposes, management control, planning purposes, as well as for feeding improvement and transformational projects. Little of this data collection is actually exploited for optimizing the ongoing operations and feeding the operational decisions. The third WMS functionality is deterministic rough cut capacity planning, based on distribution requirements planning style computations. This serves in roughly estimating the daily capacity required in the forthcoming future.

The main EMS functionalities relative to order fulfillment centers are also threefold. First is order and supply management. It is in such systems that client and supplier transactions are registered and activated. It is also in such systems that materials requirements planning site-level inventory management are performed. Second is automated data collection and storage, as done by WMS, but at business level. Third is supply chain planning and management (SCP/SCM) in businesses having reached the maturity of explicitly working on mastering their overall supply chain, from their customer's customers to their suppliers' suppliers. Generally, SCP/SCM considers an order fulfillment center as one node in the overall supply network, and only deals with high level decision making and performance monitoring.

The second level of Figure 4 reveals twenty-six activity-specific live piloting functionalities. Starting with the left-most activity, Figure 4 indicates that selling oriented piloting embeds three functions.

1. Order delivery and shipment promising

   This aims to provide each client the most appropriate promise for the delivery and shipment of each of its orders, taking into account his needs and expectations (including the choice of transport mode/type), the earlier commitments by the center, the operational dynamics and capacity, as well as the inherent uncertainties (Montreuil et al. 2006).

2. Dynamic order lateness management

   Lateness is bound to occur. A responsible OFC must inform its client as soon as it is detected, hopefully prior actual realization, and explicitly deal with the client on how the situation is to be remedied.

3. Outbound loading planning

   As sales are registered and demand forecasts updated during the course of a day, this piloting functionality aims at portraying as realistically as possible the load to be expected to dynamically flow out of the center, helping piloting all internal activities as well as the outbound logistic activities, spotting surges and valleys and planning for resources. Such planning has to be stochastic, providing intervals of confidence and robust estimates instead of simple mean estimates.

Supplying and purchasing oriented piloting also embeds three functions.

4. Supply delivery time promising

This is the counterpart of the similar function for the selling activity. Provided its committed sales and actual forecasts, this piloting function has to get from the appropriate suppliers the most appropriate delivery commitments, taking time-price compromises into considerations as well as constraints and uncertainties on the supply side and the implication on the center's delivery side.

5. Supply arrival forecasting

   Provided supply delivery commitments and supply plans, as well as real-time geographical positioning information updates, this functionality aims at continuously refreshing the supply arrival estimates so as to help dynamically plan the inbound loading on the center.

6. Inbound load planning

   Provided the supply arrival forecasting, this functionality generates prospective loading plans to help piloting the receiving activities and overall prioritizing and planning of flow through the center.

Inbound logistics requires two piloting functionalities.

7. Inbound supply synchronization

   Based on the continuously updated supply supply arrival forecasts, this functionality aims at synchronizing the arrivals, in fact interacting with the transporters, the yard dispatching agents and the receiving agents, so as to make sure that the highest priority inbound deliveries get in first.

8. Multi-source inbound transport optimization

   Given supply commitments and plans, this functionality aims at minimizing transportation costs by sharing vehicle routes while respecting the timing targets, based on fresh information.

Receiving requires three piloting functionalities.

9. Dock-time assignment

   Provided supply arrival forecasting and inbound logistics synchronization efforts on one side and the inbound priorities on the other side, this functionality dynamically assigns incoming vehicles and trailers to docks for specific time slots.

10. Inbound prioritization and dispatch

    Provided on one side the outbound shipment commitments, the overall center loadings and constraints, and the inbound arrival forecasts, dock-time assignments and currently docked vehicles and trailers, this functionality constantly updates the inbound treatment priorities, dispatches resources to receiving tasks, and routes received products for further treatment or staging.

11. Quality inspection prioritization

    Ultimately, all suppliers are quality certified so that inbound quality inspections are not necessary. But whenever this is not achieved and quality inspection is required, this piloting functionality dynamically updates the priorities of products waiting to be inspected, so that high priority products are reengaged into the center's flow, aiming toward shipment.

Storage requires two main piloting functionalities.

12. Dynamic product deployment

    Whenever a product has to be staged prior further flow through the center, this functionality has the responsibility of deciding where and when to dynamically store it based on all current information on locations, commitments, decisions and estimates. A product may be put in a staging area for a while, later moved to a storage bay for some duration, and then switched to another storage bay for easier retrieval.

13. Storage-picking interleaving synchronization

    This functionality has the responsibility of minimizing overall travel necessary to insure proper deployment and retrieval of products, insuring that whenever possible empty travel are minimized by assigning a nearby pickup after a storage operation has been completed. This is continuously going on based on storage and retrieval requests as well as positional information updates.

Value added service has a single integrated piloting functionality.

14. Operations planning and synchronization

    This functionality has the responsibility of insuring that requested value added services such as packing, packaging and bundling are performed on time provided product availabilities, resource constraints, order shipment commitments and flow priorities. This involves planning resources and operations, and dynamically synchronizing the value added activities with the upstream and downstream flows through the center.

Order picking requires embeds four piloting functions.

15. Dynamic batch and wave formation

    Even though ideally, a center would get away from imposing waves and batches without losing productivity, this is not achievable in many centers. Thus the dynamic creation and deployment of batches and waves, provided all flow priorities and feasible options, is the critical responsibility of this functionality.

16. Dynamic pick sequencing and routing

    Provided the formed waves and batches, as well as all minute priorities, and positional information updates on products and pickers, this functionality dynamically sequences and routes picking operations, so as to best fit downstream priorities while maximizing productivity.

17. Dynamic picker deployment

    In tight relationship with the dynamic pick sequencing and routing functionality, this functionality's responsibility is dynamically dispatching picking humans and equipment to picks and picking routes, so as to best fit downstream priorities while maximizing productivity.

18. Global picking synchronization

    In line with wave and batch formation, this functionality insures that picking through the various zones and technologies in the center are all dynamically synchronized as best as possible to feed sorting and shipping, for example avoiding bottlenecks due to efforts having been put on getting ready products for a given shipment while part of the shipment is not picked in the right time and creates delays and space jams downstream.

Sorting requires three piloting functionalities.

19. Client-to-lane assignment

    Sortation systems often use lanes to differentiate and group client orders. There are a limited number of such lanes. Furthermore, often technology and process refrains from intermixing products from various clients or client orders on these lanes. Arriving products must either be assigned to a lane or recirculated through the system for a later try. This functionality dynamically manages all client and order assignment to lanes provided downstream priorities and upstream availabilities and incoming flows.

20. Sorter-to-lane assignment

    Human or robotic sorters can be successively assigned to distinct lanes, and each lane may be able to gain throughput capacity by adding sorters and then to reduce it by removing sorters. This functionality manages this dynamic deployment of sorters to lanes, affecting their throughput, based on downstream priorities, client-to-lane assignments and available sorters, as well as affecting overall sorting productivity.

21. Vehicle-to-buffer assignment

    Once sorted and put on transportation unit loads (pallets, returnable containers, etc.), the products often have to be staged for a while due to imperfect synchronization between sorting and shipping. This functionality has the responsibility of deciding where to store products in the pre-shipping buffer zone, assigning buffer locations to combinations of specific vehicles, clients, shipments, orders and unit loads as best fit, with the aim of minimizing handling and congestion in getting them in the buffer and then into their outbound vehicle.

Last but not least, shipping requires five piloting functionalities.

22. Client-to-route assignment

    As priorities unfold and shipment availability estimates get updated and confirmed, there is potential to dynamically decide on assignment of client orders to specific routes so as to best respect engagements while minimizing transportation costs. Whenever possible and allowed, this is the responsibility of this functionality.

23. Vehicle-to-route assignment

    Vehicles can be monolithic or can be defined as a combination of carrier-trailer. They can be owned and operated by the center's business or be owned and operated by a third party transporter. As routes are decided and as vehicle positional information gets updated as well as their expected arrival time at the center site, there is potential to dynamically assign vehicles to routes. Provided loading and travel constraints for each vehicle, as well as the flexibility contractually agreed upon, the aim is to maximize respect of commitments to clients while minimizing transportation costs.

24. Vehicle-dock-time assignment

    This functionality serves the same type of role as its inbound counterpart, making sure that the right vehicles is backed at the right dock at the right time to maximize smooth shipping and upstream operations while aiming to respect commitments to clients as best as possible.

25. Vehicle loading synchronization

    Provided the current set of vehicles docked and the product unit loads ready for shipment, this functionality dispatches shippers to loads and vehicles so as to best exploit the available resources and best contribute to meeting client commitments.

26. Transportation synchronization

    Given the vehicles ready to depart now and in the forthcoming future, this functionality synchronizes all outbound transportation. It assigns drivers to vehicles as best fit when flexibility is available. It may group vehicles into caravans when advantageous. It may physically adjust routes given time of day, road conditions and destination.

On the final fourth layer of Figure 4 are summarized the two overall functional responsibilities of the live piloting system, integrating the twenty six functionalities described above and interacting with the EMS and WMS functionalities. The first encompasses the integrated real-time intelligence-based planning, synchronization and control of all daily operational activities and resources. The second lies in the projective intelligence-based simulation-supported planning of near-future operations and capacity.

The first functional responsibility adds up all activity specific such activities, yet it emphasizes the fact that is far from being simply be the juxtaposition of the specific functions: it has day-to-day responsibility for enabling overall operational performance from the center both in terms of client service and financial performance.

This responsibility first requires that it be grounded in live feeds of hard fact intelligence. The real time information at the source of the required intelligence has to come from everywhere in and around the center. For example, it feeds from the purchasing system when new items are purchased, from the entry gate when new items have arrived, from the order management system when new sales orders are placed, and from each logistic unit within the center when scheduled activities are finished. Technologically it means direct feeds from the automated data collection and storage facilities of WMS and EMS, exploiting technologies such as scanners, voice-systems, radio-frequency (RF) systems and RFID systems.

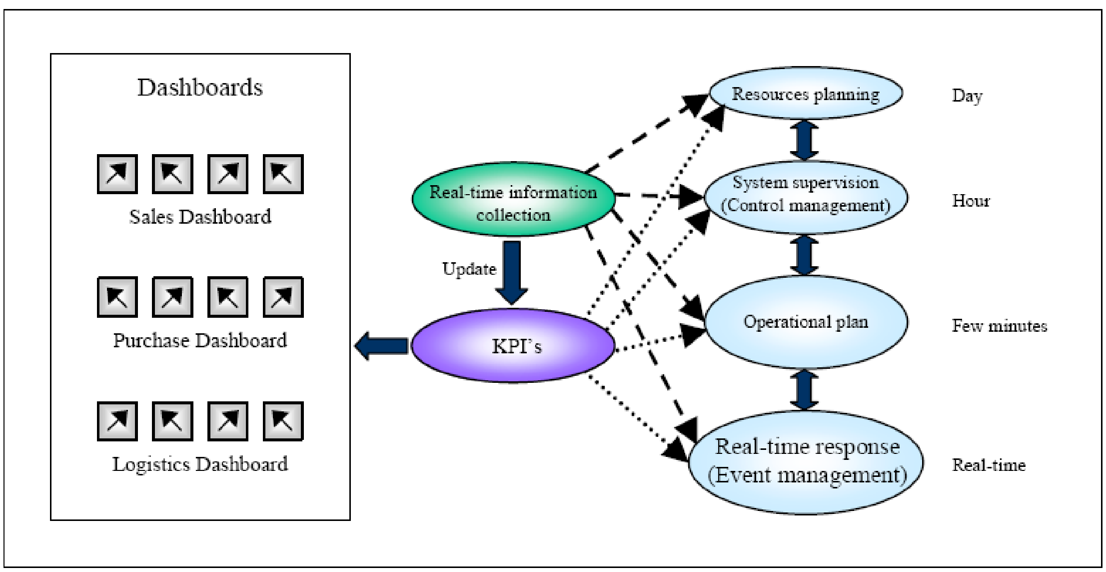

Figure 5: Informational and decisional scope of a fulfiller piloting system

Second, the responsibility requires the system to be designed to bind and align distributed decision making toward overall performance optimization. Figure 5 attempts the render the four layers of decision making supported by the fulfiller piloting system, ranging from resource planning, system supervision, operational plan and real-time response to events. Layers vary in time horizons, respectively days, hours, minutes and real-time. Yet all occur concurrently, continuously fed by real-time information collection and driven by up to date key performance index (KPI) computations. These KPIs feed the system's internal decision making processes as well as the human decision makers through performance dashboards. Furthermore, the four layers are interlaced, having mutual effects on each others. For example, when resource planning adds employees in some zone in the center, it affects both the operational plan of the zone and the operational schedule of the employees.

As suggested by many authors and reported in the previous section, the conjuncture favors privileging a conceptual architecture defined around a network of distributed agents and agent teams, interlacing focused agents with others having more holistic perspectives, and favoring an efficient interaction between human decision makers and virtual agents. Within the piloting system, virtual agents can be used for decisions that do not require direct human intervention, or for supporting humans in their decision making. Decisions for which virtual agents can be used include picking batch formation, picking orders sequencing, allocation of employees to picking orders, determination of picking routes, dynamic routing, allocation of employees to sorting lanes, as well as allocation of clients to sorting lanes. Virtual agents reduce decision making time and delays and help increase the intelligence supporting decision making processes.

The second functional responsibility recognizes that the multiplicity of distributed decisions and flow channels, coupled with the fast pace, high uncertainty, wide scope and large scale of the centers combine to make it hard to predict the outcome of planned and ongoing daily operations without actually simulating in a projective manner the near future of the center operations under a variety of stochastic scenarios.

Thus simulation based planning has to be highly realistic, taking into account the daily capacity constrained synchronization of selling, supplying and purchasing, inbound logistic, receiving, storage, value added service, order picking, sorting and shipping activities through the order fulfillment center. It has also to reflect the uncertainties related to demand, supply and internal operations. It is also critical that it embeds the actors' attempts at managing as efficiently the center's operations, aiming to meeting the shipment and delivery deadline commitments. This includes their forecasts, estimates, operating rules and heuristic decision making processes. The planning outcome must be rich, including probabilistic distributions on the number of employees dynamically needed in each of the center's zones through phases of the day, the number of sorter exit lanes needed, and the number of docks to use.

Enabling this second functional responsibility first requires that the center be virtually modeled, representing its objects and actors (including clients and suppliers) and their characteristics and behaviors. Such a simulation model is in line with object oriented simulation, which is itself in line with the agent oriented architectural approach suggested above for harnessing the first functional responsibility. Second, the model is required to be continuously fed by fact-based internal and external intelligence. This feed includes demand forecasts, actual sales and delivery commitments, supply deliveries and forecasts, product deployment through the center, employee location and status, as well as equipment location and status. Using agents, an informational and behavioral matchup can be implemented between the virtual agents really used in piloting the center and the simulation agents. The same goes between human agents and their approximate simulation agents. Similar matchup can be instantiated between physical objects and their simulation modeled objects.

It is in the combination of both functional responsibilities that the real conceptual challenge lies. In order for the simulations to have any value, their outcome must be in a position to really influence live operations through the decision making of human and virtual agents. Concerning human agents, it requires to conceive, to design and to implement smart visual interfaces with cockpits allowing them to get rapidly to the core of the advance learning gained from the simulations, to really see the linkage between the simulation outcomes and his current potential decisions, to enact and deploy resulting decisions, and to get feedback on his previous reactions to simulation outcomes in specific situations. Concerning virtual agents, it requires developing into them the smart capabilities necessary for them to analyze the simulation outcomes, ponder its decisional options and then to enact them by message passing to other virtual agents, humans or to specific equipment.

6. Conclusion

Order fulfillment centers have grown in importance, size, scope and numbers, becoming critical hubs in the demand and supply networks of many world class businesses. Such centers focus on fast paced timely preparation and outbound shipment of customer orders from a large mix of temporarily stored inbound products acquired to satisfy these orders. In order to be both price and service competitive, such fulfillers thrive on real-time synchronization and bee-hive efficiency in highly turbulent demand and supply.

Even though originally conceived for simpler slower pace warehouses and distribution centers, warehouse management systems (WMS) have been transplanted for use in fulfillers. WMSs help fulfillers survive the complexity, yet at the cost of lower productivity and service levels. Aiming to enable smart live piloting of fulfillers, this paper has proposed enhancing WMS with Business Intelligence to create a Fulfiller Piloting System (FPS), and it has described the intended functionalities of such a FPS. A FPS covers all key activities of a fulfiller, integrating and synchronizing activities such as selling, supplying and purchasing, inbound logistic, receiving, storage, value added service, order picking, sorting and shipping. A FPS exploits the real-time feed of information from both sides of the fulfiller’s demand and supply network, as well as from its internal operations. It drives for dynamic distributed synchronization of operations and optimization of decisions by a combination of human and virtual agents, with the objective of higher overall productivity and service.

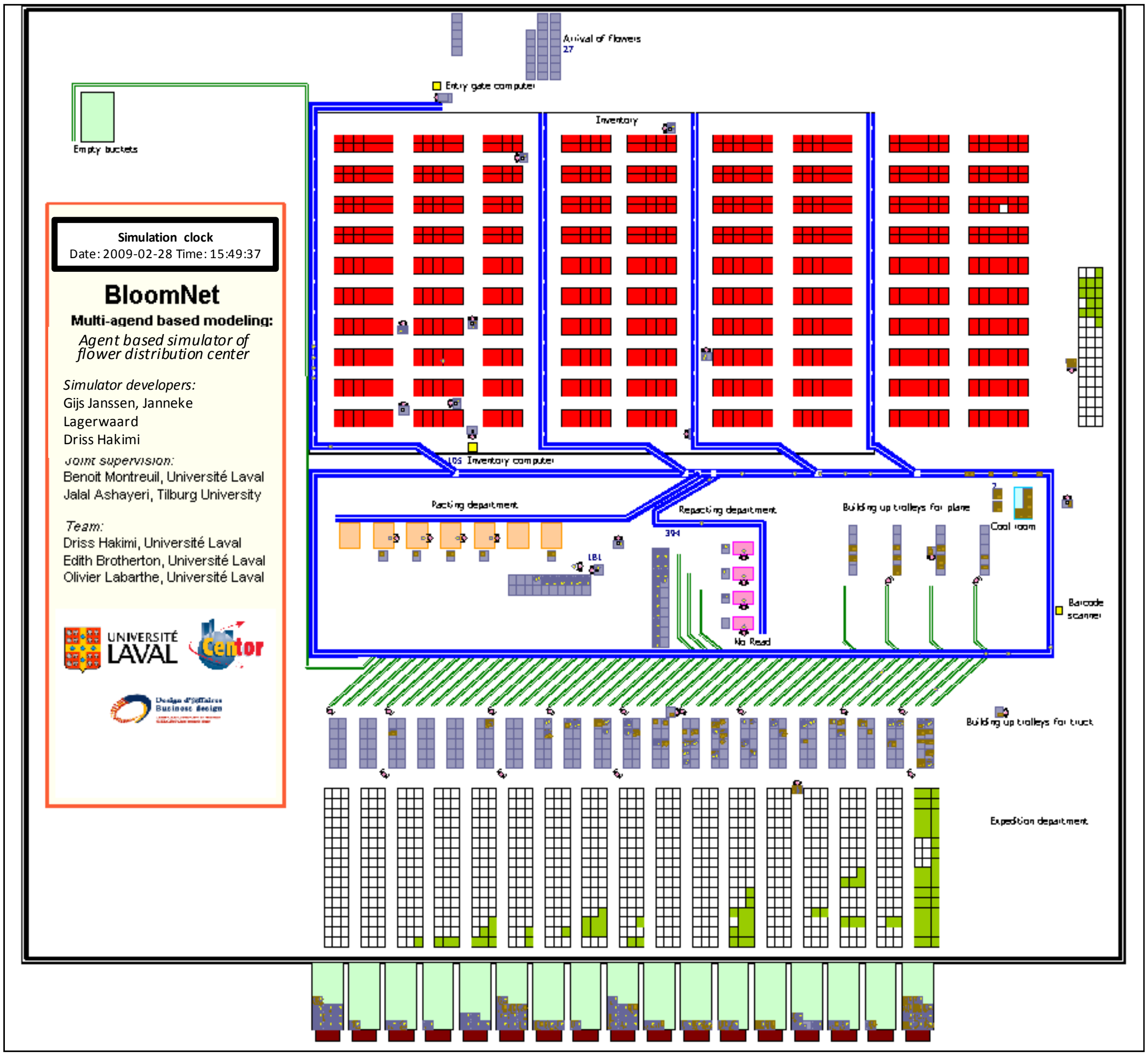

Figure 6: Holistic agent-oriented simulator of the BloomNet order fulfillment center

The actual development of a Fulfiller Piloting System is way beyond the scope of this paper and will be the subject of further research. As a first step in the research and development roadmap toward FPS realization, the authors' team has completed the design, development and validation of a holistic agent-oriented simulator of an order fulfillment center, using the BloomNet center introduced in Figure 1 for experimentation purposes. Figure 6 exhibits an animation screenshot taken during an actual simulation experiment with the simulator. Comparing Figures 1 and 6 reveals the high fidelity of the representation, with every employee, every flower bucket, every storage, sorting and handling equipment explicitly modeled. Each employee agent has reasoning capabilities and freedom of action approximating those of the modeled employees. Virtual agents have decisional responsibilities for all facets actually under the control of software modules and equipment controllers in the real world implementation.

The BloomNet simulator, when fed with demand and supply data from actual operating days, succeeds to reproduce finely the intricacies of the complex operational flow patterns, ending up with key performance indices in line with those actually registered. Through its execution, the simulator generates exhaustive databases on the center's dynamic work and flow patterns and on its dynamic multifaceted performance. Implemented through a Fulfiller Piloting System, these simulation outcomes would then be transmitted to the virtual agents and displayed to the human decision makers.

The emergence of live piloting systems for order fulfillment centers opens up a wealth of research avenues. For example, many of their proposed focused functionalities have never been researched. The underlying decision objectives and processes have not been formally expressed or mathematically modeled. Smart heuristics for enacting these functionalities are yet to be conceived, developed and tested. Once simulators become available, the interrelationships between the various functionalities can be empirically investigated, leading to deeper understanding of the systemic effects. As FPS prototypes become available, then overall consistency and global efficiency of their distributed set of decisional agents can be studied both using simulators and in pilot implementations in testbed centers.

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