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The virtual warehousing concept

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Abstract

The virtual warehouse (VW) is a state of real-time global visibility for logistics assets such as inventory and vehicles. The efficiency of the VW is comparable to that achieved in a local warehouse facility. We assess the enabling technologies, develop a conceptual framework, and identify the essential decision-support modules of a virtual warehouse. A case study for field repair service illustrates potential benefits of perfect information, in terms of reduced transportation, labor costs and service times. The case study pertains to field logistics support for business telephone systems. The productivity and utilization of highly skilled field technicians are improved substantially. A field scrap policy supported by VW reduces the volume of returns to the repair depot by over 20%.

1. Introduction

Innovative logistics and warehousing practices are essential to gaining competitive advantage in today's global markets (Fuller et al., 1993). The successful firm will identify customers' needs and overcome logistics challenges to provide excellent service. The virtual warehouse (VW) relies on information technologies and real-time decision algorithms to provide operating efficiencies and global inventory visibility comparable to that achieved in a single-location world-class warehouse (Stuart et al., 1995).

The VW provides substantial gains in accuracy and throughput, on-line material visibility for customer service, precise control of transportation, and data analysis capabilities for any users capable of accessing the virtual databases. Stock-point replenishments and trans-shipments are triggered in a *pull* mode based on instantaneous inventory position and changing service

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requirements. The VW approach makes use of real-time data on actual customer orders, minimizing the role of forecasts in execution systems.

The availability of real-time information makes obsolete many existing logistics algorithms designed to operate in batch mode. The VW opens a new era of logistics research aimed at designing adaptive algorithms that adjust dynamically based on real-time profiles of customers, suppliers, orders, locations, and capacities.

2. Conceptual framework

Conceptually, the VW consists of two levels as shown in Fig. 1 (Walker et al., 1996a,b). The data level includes hardware and software to collect and communicate real-time data. The algorithm level builds on the functional level and uses real-time algorithms to filter and process data for operational decision-making. Both levels are vital to the VW.

2.1. Data level

The data level consists of hardware and software technologies that are the foundations of VW and support the real-time algorithms. The following technologies and systems at the data level are essential for real-time data acquisition in mobile applications:
- Standard interfaces and integrated databases
- Wireless communications
- Global positioning
- Geographic information
- Automatic identification

2.2. Algorithm level

The algorithm level fully utilizes the potential of the data level through real-time algorithms for decision support. Inventory allocation algorithms aid in optimizing the stock levels and locations

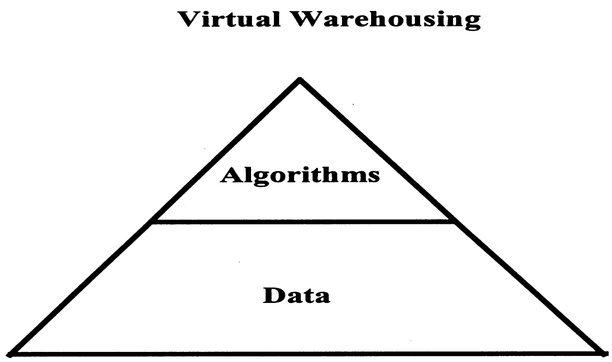

Fig. 1. Virtual warehouse components.

based on the criteria set by material planners. Point-of-use delivery and storage techniques closely link manufacturing operations to vendor deliveries by pull signals in response to point-of-sale information.

Supply chain integration algorithms manage multiple resources in the virtual logistics organization, including internal processes, external suppliers, and third-party service providers. Material-sourcing algorithms determine optimal suppliers based on quality, transportation cost, and capacity to fulfill orders on time. Priority algorithms order tasks into different levels of importance based on tailored logistics criteria such as customer service needs by customer group. Adaptive simulation allows analysis of current processes and re-planning of actions based on real-time data. Electronically tagged containers provide each successive process with information about what actions a job requires and where next a job is to be routed.

Intermodal vehicle routing algorithms optimally select transportation modes and route material through the transportation network, considering the multiple objectives of service quality, cost and cycle time. Optimal vehicle loading algorithms evaluate jobs and maximize the volume utilization while staying within weight limits. Once the optimal load characteristics are known, cross-docking processes and/or picking operations are coordinated in real time to maintain material movement onto the transportation vehicle. This degree of coordination will minimize excessive handling and enhance customer service.

Postponement transportation logic reduces customer delivery cycle times. In this mode, inventory is moving before orders are placed. The transportation mode carries an expected amount of material determined by the inventory algorithm. Before arriving at a location, the vehicle operator receives delivery notices for that location.

Merge-in-transit (full-set delivery) logic coordinates multiple loads (possibly on different transport carriers) that must arrive together at the destination. Congested area routing logic analyzes the planned route to determine whether on-time delivery is feasible and reroutes loads as necessary. Telecommunications optimization algorithms determine, in real-time, the best communication channels based on capacity, cost, and reliability.

3. Case study

This section describes the information and material flows in a supply chain for new, unrepaired and repaired business telephone sets under two scenarios: (1) conventional and (2) virtual warehouse. The supply chain includes manufacturing, distribution, installation, servicing, removal, and repair/rework. The primary focus is on the field operations of the mobile repair technician.

The VW scenario is compared to the existing conventional scenario. It is recognized that there are inefficiencies in the existing process, as in any real-world case. A possible approach is to fully rationalize the logistics process, then implement information technologies such as virtual warehousing and measure the incremental benefits. However, many possible improvements are not practically feasible. For example, relocation of facilities involves substantial costs and the resulting network may soon become non-optimal in a dynamic environment. There are also obvious tradeoffs between perfect information and capacity, such as inventory. For example, rather than investing in information technology, the firm might carry more inventory. However, space constraints, especially at use-points such as service technicians' trucks, preclude increasing inventory. Furthermore, capital markets do not reward firms that increase the asset base even if doing so has many potential benefits. Simple procedural changes often produce less than expected benefits because of an increase in non-value-added clerical workload and do not have lasting benefits without continuous management vigilance to maintain process discipline.

3.1. Field service network

Fig. 2 illustrates the closed-loop field service network, including the following nodes:
- Manufacturing and Distribution Center (PLANT)
- Repair Depot (REPAIR DEPOT)
- Material Stocking Locations (FIELD OFFICEs)
- Service Technicians (TECHs)
- Customer Service Center (SERVICE CENTER)
- National Parts Service Center (PARTS CENTER)
- Customer (CUSTOMER)

3.2. Conventional process scenario

This section describes material flows and processes in the existing (conventional) system. The field service process begins with a CUSTOMER request (1) to the SERVICE CENTER. The first decision point (2) determines if a TECH is needed. If the repair does not require a TECH, the SERVICE CENTER contacts the PARTS CENTER (3) to supply replacement components (4) to the customer. The customer then returns the defective material (5) to the PARTS CENTER, which forwards it (13) to the REPAIR DEPOT.

If the customer requires field service, then the SERVICE CENTER contacts the TECH (6) who schedules an appointment to visit the customer site. At the customer's site (7), the TECH diagnoses the problem and determines how to correct it. Once the material requirements have been identified, the TECH checks the truck for stock availability. If the material is not on the truck, then the TECH must travel to the FIELD OFFICE (8) to pick up the needed material. This step adds substantially to the repair time and may result in delaying job completion until the next day.

If stock is available at the FIELD OFFICE, then the TECH retrieves the material and travels back to the customer site (9) the same or next day. Otherwise, the material is ordered (10) from the PLANT. The PLANT guarantees shipment (11) of in-stock material within two days from receipt of the order. However, the order processing time from the FIELD OFFICE to the PLANT is two to three days.

If the material is unavailable at the PLANT, then there is an additional delay for production (12) to replenish the inventory. The production lead-time is highly variable since some products are only manufactured once a month. Items that are more popular are produced more frequently. Once produced, the material is shipped (11) to the FIELD OFFICE. The FIELD OFFICE then notifies the TECH, a second visit is scheduled to the customer's site, and the TECH is dispatched.

The defective material is returned (8) to the FIELD OFFICE. The FIELD OFFICE stores the material until there is a load to ship (13) to the REPAIR DEPOT or until storage space becomes inadequate. At the REPAIR DEPOT returned material enters a sorting process for repair and

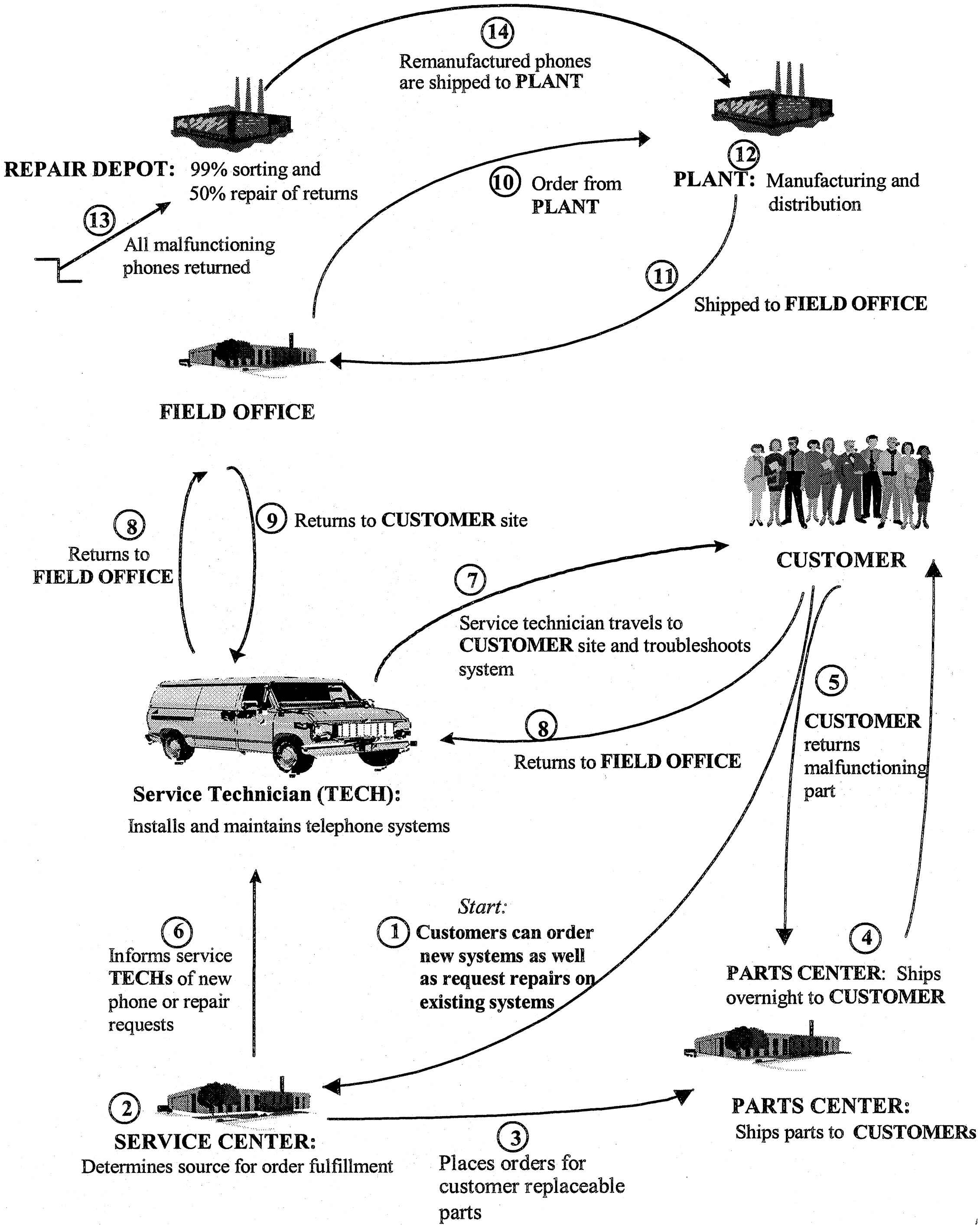

Fig. 2. Conventional information and material flow.

rework. Many returned phones are not repaired due to the poor condition or surplus stock levels. Remanufactured phones are shipped to the plant (14) for distribution.

Note that the conventional process is a supply chain that uses only two channels

(A) PLANT → FIELD OFFICE → TECH → CUSTOMER → REPAIR DEPOT → PLANT.

(B) PARTS CENTER → CUSTOMER → PARTS CENTER → REPAIR DEPOT → PLANT.

The conventional process does not have the information technology to provide global real-time inventory visibility or to share inventory among nodes at a supply chain level. The VW scenario (Section 3.3) reduces logistics cost and customer service cycle time by providing the real-time data and decision algorithms.

3.3. Virtual warehousing process scenario

Assumptions. The following assumptions were made in designing the VW flow logic:

- Second customer site visits can be scheduled during the initial visit since real-time information about material deliveries is available.
- While waiting for a shuttle to deliver material, TECHs have value-added work available either at the customer site or nearby.
- The PLANT has efficient order fulfillment processes and can serve a FIELD OFFICE faster and cheaper than can another FIELD OFFICE.
- Transportation cost is, on an average, lower for transshipment between regions than for shipment from the PLANT, since the VW will always identify the nearest region of material availability.

Material location logic. The VW provides global visibility of material locations and stock levels. Location logic first checks to see if the material is on the TECH's truck. If not, then the inventory is checked elsewhere in the immediate service area. There are four possibilities:

- Available in the FIELD OFFICE and on another TECH's truck.
- Available in the FIELD OFFICE only.
- Available on another TECH's truck only.
- Not available in the service area.

The VW scenario makes feasible material transport by a shuttle vehicle operating in the service area. The shuttle transfers materials from the FIELD OFFICE to TECH trucks and between TECH trucks. The shuttle is potentially cost-effective since the driver's wage rate is lower than the wage rate for experienced field TECHs. TECH time is more profitably utilized on the skilled tasks of troubleshooting and repair rather than retrieval of parts. The justification for a shuttle depends on the level of service activity in the area. However, a shuttle adds an element of control complexity that would be difficult to manage without the intelligent real-time algorithms of VW technology.

If the material is at both the FIELD OFFICE and on another TECH truck, then the logic determines the best source. This decision is based on distances and service time required to achieve the desired customer service level. Cost issues include:

- If a shuttle is available, should the shuttle pick up material from another TECH's truck or from the FIELD OFFICE?
- If a shuttle is not available, should the TECH retrieve the needed material from another TECH's truck or from the FIELD OFFICE?

- If a shuttle is not available, should the TECH proceed to another job and allow another TECH having the needed parts to proceed to the CUSTOMER site and complete the job?

If the FIELD OFFICE is the best or the only source of the needed material, then the availability of a shuttle is determined. If the shuttle is available, then it picks up the material from the FIELD OFFICE and delivers it to the TECH. If the parts shuttle is unavailable, then the TECH must retrieve the needed material from the FIELD OFFICE and return to the CUSTOMER site to finish repairs.

If another TECH's truck is the best or the only source of the needed material, then the availability of a parts shuttle is determined. If the shuttle is available, it makes the pickup and delivery. If the shuttle is unavailable, then the TECH travels to the job site, retrieves the material, returns to the customer's location, and finishes the repair.

If the material is unavailable at the FIELD OFFICE or on other trucks, then the PLANT warehouse is checked for the needed material. If the material is available, then it is shipped to the FIELD OFFICE. If the material is unavailable at the PLANT warehouse, then another FIELD OFFICE is checked. If the material is available at another FIELD OFFICE, then it is shipped to the local FIELD OFFICE. Otherwise, the material is produced either at the PLANT (new items) or REPAIR DEPOT (refurbished items). The material is shipped to the FIELD OFFICE.

The PLANT is queried for stock before another FIELD OFFICE, because the PLANT is assumed to have more efficient order fulfillment and distribution processes. Since a FIELD OFFICE must put priority on serving its own customers and does not have efficient distribution processes, it is considered as a source only to achieve global customer service goals. Production has the slowest response rate and is the option of last resort.

After materials are received by the FIELD OFFICE, the next step is for the FIELD OFFICE to dispatch a TECH for a second customer visit. Under the conventional scenario, a minimum of one day passes between receipt and material availability to the TECH. Conversely, with the real-time information available in VW, the TECH knows the ship date and transportation status, allowing more prompt and accurate scheduling of the return visit to the CUSTOMER site.

Return logic. If the TECH determines that lightning or other surge damage has occurred, the damaged product is returned to the FIELD OFFICE to be field scrapped. If the defective part is not damaged by lightning or other surges, then the return logic determines if the defective part should be returned or field scrapped. Under VW, it is possible to instantly evaluate global inventory status and determine whether the defective material should be returned for repair. The VW algorithms determine how to process material returns, considering inventory levels, customer service goals, production status, demand, and costs. If the inventory logic determines that the product should not be returned, then the TECH designates the product for field scrap and returns it to the FIELD OFFICE. The TECH does not scrap any units at the CUSTOMER site in order to (1) avoid customer inconvenience and (2) prevent units from entering an unauthorized after-market. Field scrap avoids the cost of unnecessary transportation. It may be more cost effective to produce a new unit of a particular product instead of returning and repairing a non-functional product. Conversely, rework may require less time. The inventory logic would address the following questions:

- Does the current inventory level throughout the system meet the current and forecasted demand and desired customer service goals?
- Is it more cost effective to return and repair a unit or to schedule the production of a new unit?

- Does production at the PLANT have enough excess capacity to produce the new product?
- Does the REPAIR DEPOT have enough excess capacity to produce the repaired/refurbished product?

Inventory levels are checked at all possible locations, including in-transit inventory, to determine if there is enough stock on hand to meet the desired customer service levels. Production status is also checked for information about quantity of product that will soon be added to inventory and near-term production capacity. The current demand and customer service levels for a particular product are needed in order to set target inventory levels.

The FIELD OFFICE receives material from the TECH and stores it. The next decision requires determining if and when to ship stored material back to the repair center. The following criteria are used to make this decision:

- Space restrictions at the FIELD OFFICE
- Economic ship quantity
- Time material has been in storage
- Priority need of material in REPAIR DEPOT
- Over-stock situation allowing field scrap in order to reduce inventory and transportation

The material remains in storage until the FIELD OFFICE is ready to process a shipment back to the repair center. If it is determined that the material should be shipped then the inventory logic is invoked to determine the current material requirements. If the material is not needed at the REPAIR DEPOT then it is field scrapped. Otherwise, the material is returned to the repair center and proceeds through the return process.

Troubleshoot benefits. In the VW scenarios, on-line documentation and help become readily accessible to the TECH. Examples of on-line documentation might include troubleshooting and repair instructions. On-line help could also consist of diagnostic programs and on-line real-time technical support by more experienced TECHs or engineers. This concept would substantially aid in diagnosing difficult problems more quickly through reduction in troubleshooting time.

Cost factors. For comparison of the conventional and virtual warehousing process scenarios, the relevant costs are assumed to be labor, transportation vehicle operation, and ordering. The sources of cost data include the case study company, The Logistics Institute (TLI), and the Mack–Blackwell National Rural Transportation Study Center (MBTC). Since the case study company's cost information is proprietary, it is necessary to report cost ranges. The relevant labor costs (including fringe benefits) are: technician travel time at a rate in the range of US$20 and US$25 per hour and shuttle driver travel time at a rate in the range of US$10–15 per hour. Note that billing rates for telephone service technicians include overhead and profit margins. It is desirable to use technicians to do repair work rather than travel, as substantial savings to company warranty expense or customer maintenance expense.

The vehicle operating costs for local service vehicles is in the range of US$0.30–0.50 per mile. Shuttle vehicles can be smaller and cheaper to operate than service vans. When it is necessary to order parts from locations outside the FIELD OFFICE, the ordering cost is assumed to be in the range of US$70–100 per order and the shipping cost is assumed to be in the range of US$5–25 per order. Actual shipping costs will depend on timing and urgency. It may be possible to add product to an outgoing stock order. Otherwise, express parcel is used. Shipping costs for return of defective product are at (1) ground parcel rates if returned by the customer or (2) less-than-truckload (LTL) rates if returned by the FIELD OFFICE.

4. Process modeling

This section describes the static and dynamic modeling and analysis for the conventional and VW scenarios described in Section 3.

4.1. Static model

Table 1 defines 10 cases for comparison of the VW and conventional scenarios. Because the case study includes proprietary data, the cost of conventional scenario case 9 is treated as the reference scenario and all other costs in Table 1 are indexed from the reference scenario. For example, the conventional scenario case 8 is 9.92 times as costly as conventional scenario case 9.

Table 1
Static analysis results

Cases	Cost				Customer service time			
	Conv[a]	VW[a]	% diff[b]	% diff[c]	Conv[a]	VW[a]	% diff[b]	% diff[c]
1. Material on truck, TECH performs service immediately	4.64	4.64	0	–	0.11	0.11	0	–
2. Material not on truck, TECH travels to FIELD OFFICE for item	9.02	9.02	0	0	0.28	0.28	0	–
3. Material not on truck, shuttle delivers from FIELD OFFICE	[d]	5.40	–	−40	[d]	0.20	–	−29
4. Material not on truck, shuttle delivers from another TECH	[d]	4.89	–	46	[d]	0.18	–	−36
5. Material not on truck, TECH retrieves from another TECH	[d]	7.54	–	−16	[d]	0.22	–	−21
6. Material not at FIELD OFFICE, order from PLANT	9.65	9.44	−2	–	2.20	1.51	−31	–
7. Material not at PLANT warehouse, order from another FIELD OFFICE	[d]	0.23	–	–	[d]	1.51	–	–
8. Material not at PLANT warehouse, order from PLANT or REPAIR DEPOT	9.92	9.71	−2	–	2.78	1.58	−43	–
9. TECH not needed, PARTS CENTER supplies item directly to CUSTOMER	1.00	0.67	−33	–	1.00	1.00	0	–
10. Material not on truck, TECH moves to another job and another TECH moves to CUSTOMER site to complete job (relay)	[d]	6.09	–	–	[d]	0.17	–	–

[a] Expressed as multiples of the values for case 9, conventional scenario.
[b] Comparison of conventional vs. VW scenario for case.
[c] Comparison of VW scenario for case vs. conventional scenario for case 2.
[d] Not a feasible option for the conventional scenario.

Table 1 illustrates the benefits of perfect information through the virtual warehouse in terms of reduced costs and service times. For every case that is feasible under the conventional scenario, cost and service time is compared against the VW scenario. For cases that are only feasible in the VW scenario, comparisons are made versus conventional scenario case 2. The static analysis is conservative in that it does not include the benefits of reduced workload at the REPAIR DEPOT due to field scrapping. The VW scenario consistently provides equal or lower cost (primarily transportation) and customer service cycle time (due to better sourcing options and instant ordering) compared to the conventional scenario. Even for case 9, the VW scenario is 33% less costly, due to transportation savings through field scrapping.

The VW approach provides several new feasible cases (3, 4 and 5) for low-cost, rapid supply of items from available sources within a service (FIELD OFFICE) area. All three of these scenarios are cheaper and faster than the conventional approach of the TECH returning to the FIELD OFFICE for other material (case 2). Having visibility of stocks at all locations and using a shuttle for delivery of replacement parts reduces cost by 40% (case 3) or 46% (case 4) compared to case 2.

Even when material is ordered from a central source (case 8), the VW information provides the potential for significantly improved customer service time, through advance scheduling that enables the TECH to return to the customer on the same day as order receipt.

Sensitivity analysis on the static modeling results showed system cost to be more sensitive to the following three variables: (1) field service technician labor cost/hour, (2) overnight express shipping cost per shipment, and (3) warehouse and shuttle operator labor cost/hour. There is a rule of thumb in maintenance management that field repairs cost an order of magnitude more than original distribution. The technician charge rate is approximately an order of magnitude larger than other labor rates. This rate differential provides a strong incentive for the use of a shuttle operator to deliver parts rather than the TECH always retrieving them, assuming the TECH has other productive work. Overnight express shipping rates affect the cost of direct PARTS CENTER-to-CUSTOMER delivery, as well as priority trans-shipments among nodes of the virtual warehouse.

Customer service times were sensitive to the transit times between: (1) FIELD OFFICE and CUSTOMER, (2) PARTS CENTER and CUSTOMER, (3) PLANT and FIELD OFFICE, and (4) FIELD OFFICE and REPAIR DEPOT. These results suggest the strategic value of logistics network modeling to determine optimal locations and transportation. However, this case study focuses on the tactical value of perfect information within the constraints of the existing network.

4.2. Dynamic model

To better understand the dynamics of VW for a field service application, the scenarios were modeled using the Simnet II (Taha, 1988) discrete-event simulation tool. Simulation analysis focuses on customer service times for shuttle-supported cases (3 and 4) and TECH relay case (10) versus case 2. VW scenario cases 3 and 10 provided statistically significant improvements over conventional scenario case 2 at the 5% level. TECHs made three times as many trips to the FIELD OFFICE to replenish parts under conventional scenario case 2 as were required under VW scenario cases 3, 4, and 10. The number of units returned to the REPAIR DEPOT under the VW scenario were 26% fewer as a result of field scrapping.

The dynamic modeling provided insights about other factors that affect cost and service, and are more manageable under the VW scenario. Sensitivity analysis demonstrated that inventory on the TECH truck plays an important role in the customer service times. The real-time information from VW enables better decisions and truck stocking mix and levels. If the service level provided by the truck stock is reduced from 90% to 50%, then the customer service times increase in the range of 300–800%. Diagnostic accuracy is another important factor. A 50% increase in the number of misdiagnoses resulted in customer service times that were 12–33% greater. As noted in *Troubleshoot benefits*, the VW data level informational facilities may be used to provide better troubleshooting and diagnostic support.

5. Conclusions

The virtual warehouse is a state of global resource visibility, based on real-time acquisition and processing of operational data. Information available in the virtual warehouse has the potential to reduce cost and improve customer service. The infrastructure is now available to capture real-time data, and the cost of data acquisition will continue to reduce. The challenge for logistics researchers is to develop fast algorithms and interactive decision-support systems to fully exploit the potential of real-time global visibility.

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