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AS/RS AND WAREHOUSE MODELING

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ABSTRACT

The computer simulation of Automated Storage and Retrieval Systems (AS/RS) and warehousing systems often present the modeler with numerous issues dealing with modeling strategies. The modeler must decide the level of detail needed to represent the various components of the system in order to obtain results which can be used in the evaluation process. This paper presents some of the warehouse components to be considered in modeling warehouse applications. It then discusses the different objectives modelers have in modeling storage facilities and the general concepts behind three modeling approaches which vary in complexity. The paper concludes with an example of the detailed warehouse modeling approach for tracking individual products and storage locations.

1. INTRODUCTION

The movement away from the high work-in-process (WIP) staging to the just-in-time (JIT) supply concept has not diminished the need to store materials. The demand for storing products may be reduced for some industries, but the demand may be kept high for others such as the food industry. Certain environments, such as distribution and manufacturing, require the need for efficient storage facilities for storing finished goods, raw materials or WIP materials. Furthermore, the rigid time constraints placed on the delivery of goods by the JIT approach increases the need for effective warehousing strategies.

In analyzing complex warehousing systems, it is difficult to foresee how the interactions between the equipment and the control logic will affect the system's performance. The control logic and variability associated with these complex systems can be studied and evaluated using computer simulation. It is important to identify if any inefficiencies exist in the proposed control logic driving the system prior to installation. Furthermore, the need to model such complex systems has become an important issue due to the increasing costs of warehouse equipment (e.g. specialty vehicles, system controls).

2. CHARACTERISTICS OF WAREHOUSING SYSTEMS

Warehousing systems are used in many environments such as product distribution centers, storage of work-in-process materials in manufacturing and for the testing of electronic equipment. All of these systems, whether manual or automatic, share the basic warehousing functions of receiving, storage, and retrieval of materials. Although the philosophy behind these applications are similar, the characteristics of each system may vary greatly. The following are some of the components and control issues affecting the performance of warehousing systems.

2.1 Vehicles

Vehicles used for storage and retrieval of materials range from forklift trucks, man-on-board cranes, to fully automatic vehicles. For each type of vehicle, variations exist in horizontal and vertical velocities as well as in the acceleration and deceleration rates. The zoning of the vehicles may play an important role which may require consideration when modeling such systems. Vehicles within these systems may share aisles or be dedicated to one or more aisles. If the operation of the vehicles includes operators, then it may be important to model breaks in order to observe the impact of changing vehicle availability. The reliability (failures) of the vehicles may also need to be considered, as well as the down time due to maintenance, battery changing, or recharging.

2.2 Inventory Control Strategy

Warehousing systems vary in the methodology of inventory control. For example, the storage of perishable goods may use the First-in, First-out (FIFO) policy, while the deep lane storage of bulk goods may use the Last-in, First-out

(LIFO) method. Also, many systems incorporate priority schemes based on production requirements and due dates. Simulation can be an effective tool in evaluating these different inventory control approaches. Providing forecasted reorder quantities and the system status (inventory) as inputs, simulation can also be used to report anticipated inventory levels throughout the forecasted time period.

2.3 Material Zoning

The storage criteria of the materials to be handled through the system may play an important role in evaluating the performance of the warehousing system. Specific material may have certain weight or height requirements which may limit the areas in which these products can be stored. If these products are high volume items which require certain storage locations, the performance of the system can be highly effected by the operations of the vehicles to these designated areas. If the location of the material to be stored is based on fast and slow movers, then the distribution of vehicle movements will be biased towards the areas of warehouse containing the fast movers. These types of storage criteria may be important to model due the requirements placed on the vehicles within the system.

2.4 Warehouse Layout

The physical sizing of the storage area in terms of the number of aisles, levels (tiers) and columns will significantly impact the control logic, vehicle quantity and product zoning requirements. For example, if the vehicles are zoned across several aisles, then the locations at which the vehicles can change aisles could be an important factor to consider.

2.5 Control Logic

The control logic driving the system operations and regulating what material is to be stored and retrieved may be the key to the successful operations of the storage facility. The decision logic determining the appropriate location to store material coming into the warehouse is just as important as the operations of the vehicles themselves. This control logic for location selection can be based on a number of criteria, such as,the material being stored, the current aisle of the vehicle, the bin locations currently available, the location of the dropoff points, and the priority of the material being transported. Just as important as the storage methodology, is the retrieval algorithms. The decision to retrieve the required material within the warehouse when multiple product locations exist can be significant in trying to optimize the performance of the system. Another important control issue affecting the performance of the system is the logic required in assigning the next task to the vehicles within the system. The algorithms may take into account the vehicles' current position within the warehouse along with any priorities which may reside with the material to be moved as well as the material's destination.

3. SIMULATION MODELING OF WAREHOUSE SYSTEMS

The modeling of a warehouse can take many forms depending upon the level of detail the user incorporates. In determining the objectives of the simulation the user can determine the level of detail required to model each of the above system characteristics. The objectives can range from determining the number of vehicles or storage locations, to evaluating the various control algorithms within the system.

In all modeling approaches, the simulation should take into account the movement times of the vehicles based on the physical sizing of the system. In doing this, the user can evaluate different control scenarios of the system as well as the utilization of the vehicles' based on these controls. In each approach the simulation effort is designed to evaluate certain operating criteria within the system. For example, the criteria may be to evaluate the proposed control logic in order to isolate any control deficiencies or to evaluate the required number of vehicles due to the vehicle's costs and lead times.

4. MODELING OBJECTIVES

The level of detail in which to model the warehouse is highly dependent upon what the users expect to gain out of the simulation effort. The objectives of the project usually drive the complexity of the model. Based on the desired results of the system, the level of detail may vary greatly.

No matter how the various systems are configured, each system must meet certain performance objectives in order to be effective. These performance measures may vary highly due to the system's design objectives. For instance, the performance criteria of one system may be to keep the utilization of the vehicles high, while the measure in a similar system may be to see if the vehicles can handle the peak demand placed on them in a specified time period. The measures used are normally defined in the design phase of the project in order to set the initial sizing and performance characteristics of the system.

4.1 Facility Design

Initial modeling efforts may be used to evaluate the sizing of the storage facility. At this level the user may want to determine the number of vehicles required to handle the expected quantities of materials. This is often an important design issue due to the cost and lead times for specialty vehicles. The user may also want to model the interactions of the warehouse with other areas of the facility in order to see how the system responds to the variability of the system components. For example, the input or output of materials from an Automated Storage and Retrieval System (AS/RS) may be performed by an Automated Guided Vehicle System (AGVS). In this case the user may want to analyze the demands placed on the AGVS as well as the AS/RS.

4.2 Control Logic Evaluation

The controls required to operate the system vehicles and to determined the appropriate storage and retrieval locations are often tested in the simulation phase. The purpose in testing the control logic is to identify if any deficiencies exist in the controls which may cause inefficiencies or bottlenecks within the system. It is often important to evaluate such controls when the system includes decisions based on priorities in order to observe how the prioritizing of materials affects the system performance.

4.3 Capacity Analysis

In many cases simulation is used to evaluate the systems capacity under various conditions. Simulation is an excellent tool in evaluating how the real system will respond under peak conditions. In warehousing applications, these peak conditions may help to determine the number of vehicles required or even the number of storage location at specific heights required to handle the incoming and outgoing materials. Also, simulation models can be used to perform best and worst case analyses along with the system's capacity to recuperate from system failures..

4.4 Time Varying Demands

Often, the performance of the systems is highly time dependent. The variability of operations may be based on the time of day, the shift of operations, or the current week or month. In each case, it is often important to model the peak conditions in order to understand how the system will react to the demands placed on it. It is also important to see how these periods affect the other systems interacting with the storage area.

The performance of the system may vary do to the product mix and the storage requirements of each product. Therefore, it may be necessary to model the demands placed on the system due to the shift in product mix over time.

4.5 Future Requirements

Simulation is one of the best tools for evaluating proposed changes in the system. Whether the changes are related to the vehicles, storage locations, control logic, or demand, simulation can assist in deciding how these changes will impact the system's performance.

5. SELECTING MODELING APPROACH

There are many approaches to modeling warehouses and their components. No one method can be considered better than the other. The most important aspect of each approach is that the models are developed at the level of detail required by the user in order to make accurate decisions based on the interpretation of the simulation results. The following sections describe three (3) approaches in modeling storage and warehouse environments. Each approach involves a different level of modeling detail and will be discussed separately. It should be noted that the user can select different concepts from the ones presented in order to develop a simulation model which meets his/her requirements.

5.1 Aggregate Warehouse Modeling

In some situations it is not very important to model the intricate details pertaining to the storage of material. This aggregate approach treats the warehouse as a black box and is often used when the storage system is not the key element involved in the simulation. For example some electronics industries use storage system to hold and test electrical components for a specified period of time. Here, material is sent into the storage area for a predefined period of time. Once the testing time has elapsed, the material is then released back into the system. In this type of environment, it may not be necessary to model all the details associated with the transfer of materials into and out of the storage area. This due to the similarity of products going into storage and the predictability of the system due to the small variability in the storage time.

Due to the reduced level of detail needed, all that may be required is to identify the input rate and the length of time to store the material. This general approach can also be modeled by just the input and output rates into the storage area. By adjusting these rates to represent the variations in demand associated with the systems operations, the user can monitor the level of inventory from a gross perspective.

In this broad modeling approach, the modeler may wish to capture the limited resources contending for the storage and retrieval tasks (e.g. system vehicles, operators). Here the modeler may wish to hold the resources for a specified period of time reflecting the time to store or retrieve the material. This delay for the storage or retrieval time could be represented through the use of a probability distribution function. Once the storage or retrieval has been completed, then the limited resource can be released to perform the next task.

The technique discussed above can be used to determine the amount of buffer space required to handle the expected incoming materials. Not only can the modeler get a grasp on the input space required, but the output rate from the storage facility can help determine the requirements of the system downstream.

This method can be used successfully when the identity of the materials going into and out of storage does not play an important role in the modeling effort through the storage area. For example, the transportation of material to and from the warehouse may be performed by an AGVS. In the simulation model, the user may wish to determine the utilization of the Automated Guided Vehicles. In this scenario, only the input and outputs which require the operations of the AGVS are important in modeling the system.

Developing models in this fashion prohibits the modeler from evaluating the control logic required within the warehouse system. The control logic required for the vehicle task assignments and product storage and retrieval algorithms are as important, in determining the system's performance, as the number of vehicles in the system.

5.2 Warehouse Zoning Approach

Often when modeling certain applications it is necessary to retain information about the material being stored and its location during the execution of the simulation model. The level of detail in tracking this information can make the modeling effort quite complex and time consuming. The user can simplify this approach by dividing the warehouse into zones for use in the simulation model. The zones could be divided in both the horizontal and vertical directions, thus enabling the user to zone the warehouse in a fashion that could represent the storage requirements of his/her products or materials.

This technique simplifies the amount of control required in tracking the number of storage locations by reducing locations into a lessor number of zones. This method permits the user to specify the zone to store material as well as keep track of the level of material stored in each zone. In this zoned approach, the movement of the vehicles can be modeled with a fairly high degree of accuracy. Here the vehicles will move between zones, instead of moving between each bin location. The movement time of the vehicles can be represented by moving from the center to center of each zone location. Once the movement is complete then the delay for storage or retrieval can be determined by a distribution associated with storing or retrieving the material from any location within that zone.

In determining the number of zones required, the user may wish to divide the warehouse into components of equal storage size. If each zone is identical in storage size, then the control routines written for one zone can be applied to the remaining zones. The number of zones is highly dependent upon the level of control the modeler requires in the model.

This method provides the modeler with a high degree of control over the storage and retrieval vehicles. With this approach the current zone locations of the vehicles must be kept during the execution of the simulation in order to determine the travel time between zones. Also with this approach, the modeler can implement the zoning and control logic for vehicles in a multi-vehicle system.

The zoning process can be used when the modeler is interested in capturing the vehicles' operations in enough detail to determine the quantity required in the system. It is also applicable when the products or materials to be stored may have certain constraints limiting them to specified areas or tiers within the warehouse. Therefore, the modeler can account for the product differentiation by assigning the storage zone which meet the product's storage requirements.

This approach can be modeled within the realm of the simulation language itself. If complex controls are required for the vehicles' operations, then the modeler may wish to control the vehicles by writing the logic in a high level language such as FORTRAN of C. In some instances, the code developed for the simulation may be used as a basis for the code in actual implementation.

5.3 Detailed Modeling Approach

The most detailed method of modeling a storage facility is to model every bin location and product stored within the warehouse. The modeler can specify the product storage requirements based on weight or height characteristics, thus controlling the distribution of material storage locations. This approach also enables the user to control the exact movements of the storage and retrieval vehicles. Therefore, the precise time for a vehicle to move in both the horizontal and vertical directions can be determined.

This form is very useful when the simulation model is to incorporate the variability in product storage requirements and product mix during the simulation run. Therefore, the modeler can observe the variability in the system performance due to the shift in products requiring different storage locations. This approach is also useful in distribution center applications where the demand for various products or materials changes due to seasonal influences.

This detailed modeling effort can be used when the modeling objective is to verify the distribution of product storage and the performance and quantity of the vehicles. This method enables the user to play what-if analyses with product storage assignments and vehicle zoning to determine the vehicles' performance. This level of detail also enables the modeler to incorporate the detailed control logic for determining the locations for storages and retrievals, as well as the vehicle tasks assignment logic.

Due to amount of record keeping for tracking the information on individual products or parts within the storage facility, the modeler may be required to store this information external to the simulation language. A high level language, such as FORTRAN or C, can be integrated with the simulation model code in order to retain the information required to store and retrieve the materials.

The following section presents some of the concepts and data structures used for modeling a storage system in detail.

6. EXAMPLE: DETAILED WAREHOUSE MODELING APPROACH

The following example describes one of the approaches used in modeling a storage facility. The modeling methodology incorporates the interactions between the simulation language and user written routines which contains the control logic and data requirements for tracking the warehouse inventory. The example includes references to the SIMAN simulation language and FORTRAN programming language.

The techniques described below have been used in various SIMAN models in order to evaluate the performance and controls of large Automated Storage and Retrieval Systems. The size of these systems have ranged from over 20,000 storage location to 3000 storage locations.

One of the first tasks in developing the logic for monitoring the exact location of the products, was to develop an approach which would minimize the amount of time in searching the storage facility. If the facility contained a large number of storage locations (e.g. 5000 to 10,000 bins), then the execution time of the simulation could be substantial if a slow search algorithm was employed. Once the approach was developed, the next task was the implementation of the approach. This involved identifying the information and data requirements needed for monitoring and tracking the entire inventory. The example to be presented consists of the following warehouse configuration:

10	Storage aisles
50	Column positions in each lane
5	Tiers (levels)
5000	Total bin locations

6.1 Identifying Bin Numbering Scheme

In order to determine an efficient method for tracking the material through the warehouse, a numbering scheme was developed which would aid in determining the location of every bin. The following numbering pattern was used in the system:

Aisle 1:	Bin Locations	1 - 500
Aisle 2:	Bin Locations	501 - 1000
Aisle 3:	Bin Locations	1001 - 1500
	.	
	.	
	.	
Aisle 9:	Bin Locations	4001 - 4500
Aisle 10:	Bin Locations	4501 - 5000

This numbering approach assumes that the bin locations directly across from each other within an aisle are identical for the storage of material. There are 500 bin locations within an aisle (250 bins on each side of the aisle). Figure 1 shows the numbering of bins on the first rack face of aisle one. By following this numbering system for all 5000 bin locations, transformation routines were developed for identifying the exact location based on the bin number. The following are the transformation equations for this 5000 bin location example. The first and third series of formulas utilize FORTRAN's integer arithmetic for truncating the decimal places. The second and third equations utilize FORTRAN's MOD function. This function returns the integer value of the remaining fractional component when dividing the first operand by the second operand of the MOD function (e.g. MOD(12,5) = 2).

```
Aisle Number:
        iaisle = (Bin # -1)/500) + 1

Column Location:
        icolumn = MOD(Bin #,50)
        if (icolumn.eq.0) icolumn = 50)

Level Location:
        icheck = MOD(Bin #,250)
        if (icheck.eq.0) then
                ilevel = 5
        else
                ilevel = (icheck-1)/50 + 1
        endif
```

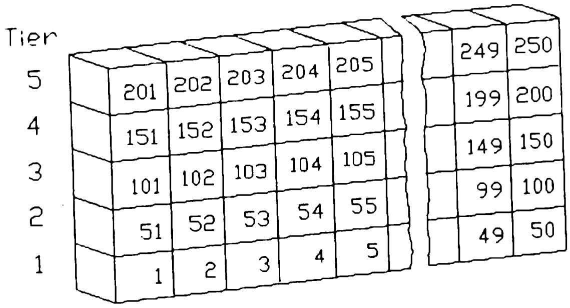

Figure 1: Numbering Storage Bins

Table 1 provides some examples of the transformations from the bin number to the exact locations within the warehouse.

Table 1: Examples using Bin Transformation Routines

Bin No.	Aisle	Column	Level
17	1	17	1
634	2	34	3
2750	6	50	5
3752	8	2	1
4998	10	48	5

6.2 Data Structures

Once a numbering scheme has been developed for identifying the bin locations, a method for tracking the material is required. The method used for tracking the inventory uses a linked list data structure. This method also will help in reducing the time to execute the search algorithms. The linked list approach used here utilizes three FORTRAN arrays. The first array NUMBIN represents each individual bin location; the second array NOPART identifies the products stored within the warehouse; and the third array NOTIER records the number of bins available within each aisle at each tier. The contents of these arrays are described below.

NUMBIN(5000,3)

5000	->	pointer to each bin location
1	->	successive bin location of the same product type : if value equals -1, no successor exists
2	->	preceding bin location of the same product type : if value equals -1, no predecessor exists
3	->	number/date sequence for identifying oldest and most recent product placed in storage. if equals 0 : bin available if equals -1 : bin reserved for product storage

NOPART(300,2)

300	->	total number of different products stores in warehouse facility
1	->	pointer to the bin location number in the NUMBIN array for the oldest product stored in the warehouse of the product type. (if value equals -1 : none of that product exists in warehouse)
2	->	pointer to the bin location number in the NUMBIN array for the most recent product stored in the warehouse of the product type.

NOTIER(10,5)

10 -> aisle locations 1 to 10

1-5 -> identifies tiers 1-5 within each aisle and records the number of bins currently unoccupied at that tier.

6.3 Control Logic for Storing or Retrieving Material

The decision logic for determining where to store material must be defined and the first aisle to check for an available bin location must be determined. This starting point may be based on the current location of the vehicles, the quantity of material within the aisles, or the last aisle in which a product was stored.

The logic for retrieving material may be as simple as identifying the oldest dated product stored in the facility to be pulled. Other more complex rules may exist, such as identifying the product locations based on the current location of the vehicles, attempting to balance work among the vehicles, or identifying the closest product stored near the drop locations.

6.4 Product Storage Criteria and Initializing Storage

In order to manage the storage locations of the various products within the facility, a means of specifying the product storage constraints is required. In this example, the storage requirements of the products are specified by restricting certain products to specific levels (tiers). Table 2 contains sample data for specifying the storage requirements by product type. The products are specified in a numerical sequence for storing the information in FORTRAN arrays for use in the simulation model.

Table 2: Product Storage Requirements

Product No.	Preferred levels	Initial Inventory
1	1 2 3 4 5	125
2	4 5	17
3	1	8
.	.	.
50	1 2	42
.	.	.
200	5 4 3	20
.	.	.
250	5	34
.	.	.
300	1 2	46

The average inventory column for each product in Table 2 will be used for initializing the warehouse storage levels at the start of the simulation. By knowing the total average inventory in this column, the modeler has the capability of using a scale factor for setting the amount of material to be in the warehouse at the start of the simulation. This approach can represent how full the warehouse is based on the time of year. This method also assumes that the ratio of product mix remains fairly constant. This preloading scheme can help in reducing the warm up time to reach steady-state operations within the simulation model.

6.5 Array Manipulation for Performing a Retrieval

When a product has been designated to be retrieved prior to the actual physical removal from the storage bin, the information pertaining to that specific location must be protected. This is required in order to avoid duplicating retrievals from the same storage location. This could happen during the time in which a vehicle is enroute to that storage bin for the initial retrieval. Then, during travel time, a second retrieval is generated requiring the same product type from the same bin location. To insure this event will not occur, the bin location is removed from the linked list which eliminates it as a candidate for future retrievals.

An example of the linked list approach and the array values associated with the storage of a specified product can be seen in Table 3. In reviewing Table 3, there are 4 bin locations which contain product type number 17. The values of the NOPART array indicate where the linked list starts and finishes for that specific product type.

Table 3: Linked List Example for Sample Product Type 17

Product Type : 17   NOPART(17,1) = 2293
NOPART(17,2) = 4672

NUMBIN Bin No.	1 Successor	2 Predecessor	3 Date
.	.	.	.
45	867	2293	22
.	.	.	.
867	4672	45	47
.	.	.	.
2293	45	-1	22
.	.	.	.
4672	-1	867	83
.	.	.	.

If a retrieval for product type 17 is required, then a search of the linked list will be required in order to find the desired location for the retrieval. In this example, the oldest of the product type will be retrieved first. The third index of the array NUMBIN contains an integer date assignment. The smaller the value is in this field, the older the product. The search would begin with the bin location stored in the array NOPART(17,1). A sequential check would then be performed through product 17's linked list in order to find the oldest product bin location. In the example there exists two location with the oldest date of 22. In this case the modeler can use the bin transformation equations to determine which location is the best. Suppose that bin location 45 was selected as the best location to perform the retrieval. It would then be necessary to remove that bin location from product 17's linked list sequence in order to avoid a duplicate retrieval as previously mentioned. This is done by switching the predecessor and successor pointers for those bin locations surrounding the selected bin. Table 4 displays the new series of array values for the 3 remaining bin locations. The only values changed are those values which have boxes surrounding them. It can be seen that bin location 45 no longer exists in the linked list for product 17.

Table 4: Reserving Linked List Bin Location for a Retrieval

Product Type : 17 NOPART(17,1) = 2293
NOPART(17,2) = 4672

NUMBIN Bin No.	1 Successor	2 Predecessor	3 Date
.	.	.	.
45	867	2293	22
.	.	.	.
867	4672	2293	47
.	.	.	.
2293	867	-1	22
.	.	.	.
4672	-1	867	83
.	.	.	.

It should be pointed out that if bin location 2293 was selected, then the value in the array NOPART(17,1) would be updated to bin location 45. Once the material is physically retrieved from the desired bin location, then the date field for that bin location will be set to zero (0) indicating an available storage location.

6.6 Array Manipulation for Storing Materials

A technique similar to the above retrieval process exists for the storage process. When a products is to be stored within the warehouse, a bin location must be found which meets the product's storage requirements. This is done by performing a check of bin locations at the desired levels in order to find an available bin. An initial aisle location must be determined within the control logic. Then a search of available bins must be performed for the desired level. Decision rules must exist for identifying the best bin location when numerous bins are available within an aisle at the same required level. Also, when no bins are available at the original aisle and level, rules must exist which determine how to proceed with the search in order to locate an appropriate bin location.

In order to demonstrate this approach, the information for product type 17 listed in Table 3 will be used. A pallet of product type 17 is destined for storage. The search algorithm searches the NUMBIN array within a designated range of bin numbers in order to find an available bin. The range of bin numbers represents acceptable bin locations for product type 17. An available bin is located when the third field of the NUMBIN array for that bin location contains a zero value. For example, A search of the bin locations is performed for product type 17. Bin location 4700 has been identified as the bin to store the pallet of material. Now a problem similar to the retrieval process exists. The bin location must be reserved so that no other materials will be sent there during the delivery of the original pallet. This is done by placing the value of -1 in the array NUMBIN(4700,3). Table 5 shows the values for reserving this bin location along with the current linked list for product type 17. The values in the successor and predecessor fields have no meaning because they are old values associated with the previous product's linked list which was stored in bin 4700.

Table 5: Reserving Linked List Bin Location for a Storage

Product Type : 17 NOPART(17,1) = 2293
NOPART(17,2) = 4672

NUMBIN Bin No.	1 Successor	2 Predecessor	3 Date
.	.	.	.
45	867	2293	22
.	.	.	.
867	4672	45	47
.	.	.	.
2293	45	-1	22
.	.	.	.
4672	-1	867	83
.	.	.	.
4700	18	333	-1
.	.	.	.

Once the pallet has been delivered to the bin location and physically placed in storage, then the linked list array must be updated. As previously described the linked list is a sequential dated list of like products. Therefore, it is possible to introduce into the system a pallet of a specific product type in which the date falls between the oldest and the most recent dates for that product. In this case the linked list would need to be searched to find the bin locations in which the product falls between in order to insert it in the linked list. For example, say that the date associated with the pallet of product type 17 has the integer value of 62. This value falls between the oldest and the most recent of the current product in storage. Table 6 displays the new values of the linked list for product type 17 once this pallet has been stored. All boxed values are those values which have been adjusted in order to keep the linked list in order by date assignments.

Table 6: Updating Linked List After a Storage

Product Type : 17 NOPART(17,1) = 2293
NOPART(17,2) = 4672

NUMBIN Bin No.	1 Successor	2 Predecessor	3 Date
.	.	.	.
45	867	2293	22
.	.	.	.
867	4700	45	47
.	.	.	.
2293	45	-1	22
.	.	.	.
4672	-1	4700	83
.	.	.	.
4700	4672	867	62
.	.	.	.

6.7 Integrating Simulation Model and Control Logic

The integration of simulation model and control logic for this type of warehousing application requires some planning by the modeler. The modeler must determine how to store the information with the desired material being stored and retrieved. The information pertaining to the storage or retrieval location of the product must be kept with the entity or product. This is needed due to the dual manipulation of the linked list arrays. In both cases, the arrays are altered both before and after the delivery or retrieval of the products. Therefore, during the travel time of the system vehicles, the information pertaining to the bin location cannot be lost. This information can usually be kept with either the vehicle or within the attributes of the entity driving the simulation model.

7. CONCLUSIONS

The modeling of warehousing applications can be performed in various levels of complexity. Based on the user's objectives in evaluation his/her system, the level of modeling detail can range from a very aggregate level approach to the detailed modeling of each individual warehouse location. The techniques applied to the different approaches in modeling these types of systems vary greatly in complexity and effort required for implementation. The modeler can pick and choose from the techniques and approaches provided in order to reach the desired level of control required for the simulation model.

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