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PERFORMANCE ANALYSIS OF MINILOAD SYSTEMS

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ABSTRACT

A miniload is an automated storage and retrieval system which stores small parts in bins or totes. The system consists of racks with a central aisle along which a computer controlled stacker crane travels to store and retrieve the bins. These systems are typically used in order picking applications, or in manufacturing support for the storage of tools and small parts.

This paper describes a simulation model of a single aisle, single pickup and delivery location miniload system. The model can be used to predict system parameters such as dual cycles per hour, crane and operator utilization and distance traveled by the crane. One can use the model to help design a miniload system that is capable of meeting or exceeding a given number of dual cycles per hour. This can be done by varying the height and length of the aisle, crane speeds, and/or storage policies. Examples will be used to demonstrate this design capability.

The simulation model is written in SIMAN (Pegden, 1985) and the data support programs in FORTRAN. All elements of the model run on an IBM PC.

1. INTRODUCTION

The Material Handling Industry is growing at a faster rate than the general economy. This growth is partially due to the general upturn of the economy, but more significantly, because of the recognition of the importance of integrating Material Handling Systems into automated factories and the importance of controlling stock levels in distribution operations.

Statistically, materials management occupies 55% of factory space and 25% of production hours. Of the total time that materials are in the plant, 87% of that time they are the responsibility of materials management. In an effort to reduce the cost of material handling in the plant, managers have turned to highly automated equipment. This has led to an increased interest in material handling systems such as Automatic Storage and Retrieval (AS/R). A recent study by Business Trend Analysts indicates the sales of AS/R systems to increase by 500% by 1994. This would make AS/RS a one billion dollar industry, five times what it is today. According to Rygh (1983) there are three basic types of AS/RS: (1) unit load, (2) work-in-process and (3) order picking. The unit load was the first AS/RS and has been the subject of many research papers. The same attention has not been given to the handling of small parts (work-in-process and order picking) which often accounts for over 90% of manufacturing support stock. Further, because of the high value of some of these small, intricate and high-tech parts, it is estimated that 75% of total stock value resides with these parts. Wenzel (1979) indicates that small parts handling has not received attention in proportion to its relative importance and suggests that the unique properties of a "less than unit load" system should be reflected in any model used to economically design an order picking, automated warehouse system.

In the following sections of this paper we will describe a simulation model for a single aisle miniload AS/R order picking system. The model's ability to evaluate various system design parameters will be demonstrated via examples. This will include both hardware (length and width of aisle, crane speeds in X and Y, etc.) and policy (storage policies, crane operation mode, types and timing of picks, etc.) parameters.

2. DESCRIPTION OF MINILOAD SYSTEM

The miniload system modeled is composed of a single aisle which has a computer controlled stacker crane. The crane travels in the aisle to store and retrieve the bins. At the head of the aisle is a single pickup and delivery (P&D) location with three positions; left, right and center (LRC). Bins are stored on both sides of the aisles. An aisle is broken into bays (the columns of bins) and tiers (the rows). The depth of a bin is constant for a given system but the width and height may vary. However, the width is constant within a given bay and is often times constant for the system. The height of a bin can vary greatly within a system.

Demands for bins are sent to the stacker crane. The crane will bring the bin to the P&D and deposit it in either the right or left position. (For special picks, which will be described later, the crane may hold the bin in the center position.) The crane performs dual cycles whenever possible. A dual cycle involves picking up a bin at the P&D, storing it in the aisle, moving to another bin, extracting it and returning it to the P&D. Dual cycles maximize the throughput of the system.

The performance of a miniload system in terms of picks per hour depends on the speed of the crane, the speed of the operator, the types and mix of picks and the average distance the crane must travel to complete a dual cycle. A crane's speed is given in terms of acceleration, deceleration high velocity and low velocity in both the X (horizontal) and Y (vertical) directions. Positioning, extracting, inserting and other delay times impact the speed of the crane.

The standard time for the operator to do the various types of picks may also impact the performance of the miniload. Where operator times are high compared to crane cycle times, the system is said to be operator paced. The type of picks an operator must perform varies from system to system. The model described in this paper allows for four types: (1) regular pick, (2) restock, (3) cycle count and (4) hot picks. Each type of pick will require different operator time. Thus a system which has a high percentage of regular picks will out perform the same system with higher percentage of cycle counts. A hot pick is handled with top priority. The crane will pickup and deliver the bin, using a single cycle if necessary, to the center position of the P&D. After the pick, it returns the bin to the aisle.

The average distance the crane travels to complete a dual cycle depends on the parts demanded and where they are stored in the aisle. A storage policy which would store high use items close to the P&D should out perform a random storage policy since the average crane travel distance would be less.

As can be seen from the above discussion the building of a model to simulate the operation of a single aisle, single L.R.C. P&D miniload system is not trivial. In the next section, the model will be described including a discussion of how the enormous data requirement for the simulation was resolved.

3. DESCRIPTION OF THE MODEL

The model can be divided into two sections: data input and simulation. The data input section provides for the input of all aisle geometry, the storage policy, crane parameters, demands, etc. The simulation section takes the data input, performs the operations necessary to satisfy the demands, and outputs system performance data. Figure 1 shows the flow of the model. Each section is described in more detail below.

3.1 Data Input Section

As can be seen from Figure 1, the data input section is divided into four parts: bay layout, aisle layout, bin demand data and system parameters. Each of these parts carried out using an interactive program written in the FORTRAN language. Each program prompts the user for data, stores the responses and generates an output file which is used by another program in the data section or the simulation section.

3.1.1. Bay Layout

The purpose of this part of the data input section is to define each different bay configuration in the miniload system. For each configuration information is gathered on the number of bins and the vertical distance between the bottoms of successive bins. This information is placed in an output file which is used by the aisle layout program.

3.1.2. Aisle Layout

Using the bay configurations of the previous program, the aisle layout program is used to define the left and right side storage racks of the aisle. Starting with the left side the user is asked to identify each bay using one of the configurations defined in the previous program. In addition, the program prompts for the horizontal distance between the centers of each successive bay. Similar information is obtained for the right side of the aisle. The output file of this program contains the (X,Y) coordinates of each bin in the miniload system using the center of the first bay and floor as the (Ø,Ø) coordinates respectively.

3.1.3. System Parameters

This part of the data input section collects all crane parameters, the location of the P&D,

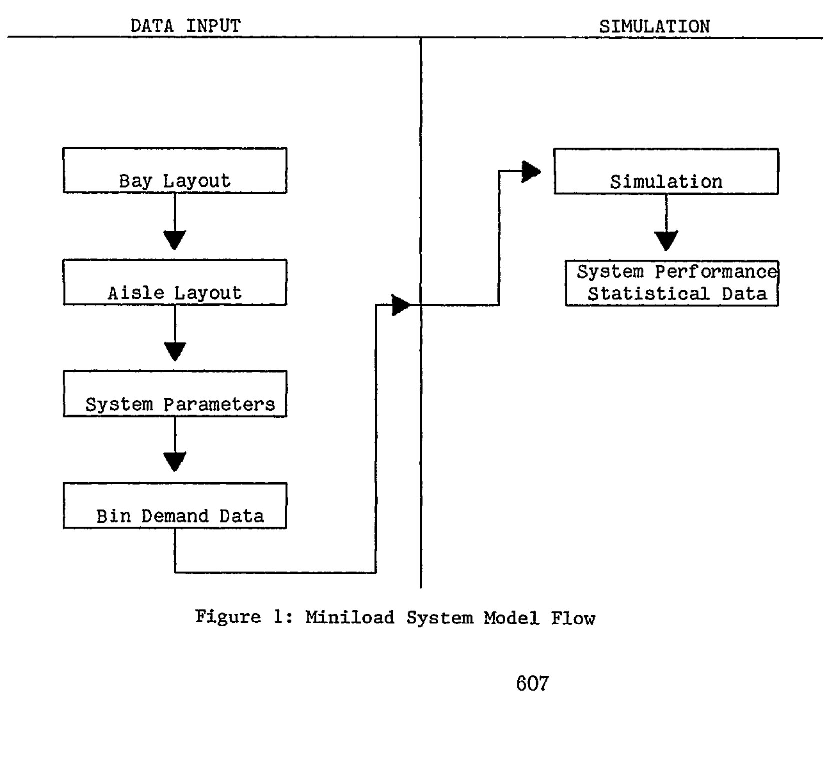

Figure 1: Miniload System Model Flow

operator standard times and simulation run parameters. The program prompts for the crane's X and Y velocities, acceleration and deceleration as well as time delays for positioning, extracting and inserting. The location of the P&D is simply an (X,Y) coordinate as measured from the (ϕ,ϕ) point. The time distributions for the operator to perform each of the pick operations is prompted for next. The present model assumes a triangular distribution for each but any distribution may be used. The final data requested are the length of timeto be simulated and the number of replications.

There are two output files generated by the program. The first is an ordering of all the bins in the system based on crane time to move from (ϕ,ϕ) to each bin's (X,Y) coordinate. The coordinates are obtained from the aisle layout output file. The second output file contains all the system parameters in a format suitable for input to SIMAN.

3.1.4. Bin Demand Data

The model allows for parts to be assigned to bins in either a random or zoned manner. In order to generate the bin demands to be used in the simulation, the program prompts for type of loading and the percentage of each type of pick operation (regular, cycle count, restock and hot) desired. For random loading the user need only give the percentage for each pick operation. Zoned loading requires more input data. The user must first define the number of zones desired (the maximum is ten). The zones are numbered one through ten with zone one being the location of high use parts. For each zone two percentages are required. The first is the percent of the total bins to be assigned to the zone. The second is the percent of the total demands for bins within the zone. The final information needed is the percentage of each type of pick operation desired for each zone.

Using the output files containing the rank ordering of the bins (if zoned loading is specified) and the (X,Y) coordinates of bins, an output file is created containing the bin demands to be used in the simulation. For random loading the demands are selected at random with each bin having an equal chance of being selected. Once the bin demands are selected each demand is assigned a pick operation typé based on the percentages specified.

Generating the bin demands for zoned loading is more complicated. The first step is to assign each bin a zone based on the desired percentages. The rank ordering of the bins is used, with zone one getting the bins closest (in terms of crane time) to the P&D. After the appropriate number of bins has been assigned to zone one, zone two has its bins assigned, etc. Bin demands are then generated based on the percentage desired for each zone. The specific bin within a zone is picked randomly. The operation pick type is assigned to each demand based on the percentage desired for each zone.

Whether the loading of the bins was random or zoned, the output file contains the (X,Y) coordinate of each bin to be picked and the type of pick operation to be performed once it arrives at the P&D.

3.2 Simulation Section

Using the system parameter and bin demand files as input, the simulation program carries out the operations of the miniload system. When the simulation starts, both P&D positions (left and right) are empty and the crane is at the P&D. The crane travels into the aisle and retrieves a bin for the first empty position then travels into the aisle to retrieve a bin for the second empty position. Thus, two single cycles are performed at the beginning of the day.

The crane waits at the P&D until the operator finishes picking the first bin. It then returns that bin to the aisle, travels to the location of the next bin, extracts that bin, and returns it to the P&D. This sequence of operations is repeated until the simulation run ends. The run will end when the specified simulation run time is reached. A new run will start and run for the specified time. This continues until the required number of replications has been satisfied. When the simulation reaches the time limit, it immediately stops. The crane does not complete its pending operation. (Note that an actual system would not behave this way; we feel the approximation will not significantly affect the results.)

Whenever the crane is at the P&D it waits until the operator finishes picking a bin before it extracts that bin. Operator pick time is determined by using the time distributions provided for the four types of picks; regular, restock, cycle count and hot. Since the crane operations are different for a hot pick, a detailed description is provided below. The other three pick operations are handled as was explained above.

The model defines a hot pick as bringing the bin to the center position and allowing the operator to perform the pick while the crane is holding the bin. Thus, a hot pick in this model is distinguished by the fact that the crane never inserts the bin at the P&D.

When the crane finishes storing a bin in the aisle, it will check for a hot pick. If a hot pick is waiting, the crane will pick that bin, travel to the P&D, and hold that bin at the center position. The model assumes that the operator will immediately stop the task he is performing to do the hot pick, then return to his previous task. After the pick is completed, the crane immediately stores the bin, then continues by checking for another hot pick.

When the crane is at the P&D and a hot pick occurs, the crane checks to see if one of the bins at the P&D is ready to be stored. If so, it stores that bin, then performs the hot pick as described above. If neither of the bins at the P&D s ready to be stored, the crane will travel empty into the aisle to retrieve the hot pick.

Hot picks are also counted as cycles in computing average cycle time. If the crane does a store before the hot pick, then the two dual cycles involving the hot pick will be shorter than normal: one will have no insert and the next will have no extract. If the crane does not do a store operation first, then a single cycle is performed. Presently there is n way to distinguish between these two cases in the model.

3.3 System Performance Statistical Data

Since the purpose of the miniload system model is to evaluate performance, the statistical data provided by the simulation program is of utmost importance. In developing the SIMAN simulation program one is free to collect any statistical data which is meaningful. Our program collects and reports the information listed and defined below.

1. Run length - the number of minutes simulated.
2. Crane cycle time - the average time in minutes for the crane to perform a cycle, discounting operator interference.
3. Cycle time - the average time in minutes for the crane to perform a cycle, including operator interference.
4. Crane travel time: P&D to aisle - the average time in minutes for the crane to move from P&D to aisle position for return of bin.
5. Crane travel time: in aisle - the average time in minutes for the crane to travel from location where bin was returned to location where bin is to be retrieved.
6. Crane travel time: aisle to P&D - the average time in minutes for the crane to travel from aisle position of retrieved bin to P&D.
7. Crane travel time per move - the average time in minutes for the crane to complete any one of the three moves described in (4), (5) and (6).
8. Crane utilization - fraction of the time crane is busy.
9. Worker utilization - fraction of the time worker is busy.
10. Count of each type of pick operation - the number of regular picks, hot picks, cycle counts and restocks done during the simulation run.

Of course other statistics may be generated by combining the above information. For example, the sum of each item in (10) gives the total picks and if we divide the sum by the run length (converted to hours) from (1), we obtain an important performance measure - picks per hour.

Each piece of statistical data can be used in evaluating design changes in a miniload system. Examples of "what-if" type questions which could be evaluated are:

(1) "What-if" the crane was faster?
(2) "What-if" the aisle was longer and not as high?
(3) "What-if" there were two operators instead of one?
(4) "What-if" zoned loading was used instead of random loading?

In the next section an example will be presented to demonstrate the workings of the miniload system model. In subsequent sections, changes will be made to demonstrate the model's ability to handle the "what-if" questions.

4. EXAMPLE

The data required for our example is presented in Tables 1-4. Note that this single aisle miniload system has twenty bays on each side of the aisle with each bay being configured as one of two possible bay configurations. Bay configuration I has 20 bins spaced vertically s described in Table 1. Configuration II has 22 bins. The horizontal distance between bay centers is 30 inches in every case. The right and left side of the aisle are identical. (See Table 2.) Table 3 indicates that the simulation will be replicated three times, each time for eight hours. The operator times are assumed to distributed according to a triangular distribution which requires the three time estimates given. The bins of our system are randomly loaded and the bins demanded during the simulation will be distributed according percentages in Table 4, i.e. approximately 80 percent of the bins brought to the P&D will require a regular pick, etc.

Bay Configuration Number	I	II
Number of bins	20	
Distances (inches):		
Floor to bin 1	15	15
Bin 1 to bin 2	7	12
Bin 2 to bin 3	7	12
Bin 3 to bin 4	7	12
Bin 4 to bin 5	7	12
Bin 5 to bin 6	7	10
Bin 6 to bin 7	7	6
Bin 7 to bin 8	7	6
Bin 8 to bin 9	9	6
Bin 9 to bin 10	5	6
Bin 10 to bin 11	5	6
Bin 11 to bin 12	5	9
Bin 12 to bin 13	5	6
Bin 13 to bin 14	5	6
Bin 14 to bin 15	10	6
Bin 15 to bin 16	12	6
Bin 16 to bin 17	12	6
Bin 17 to bin 18	12	6
Bin 18 to bin 19	12	5
Bin 19 to bin 20	12	5
Bin 20 to bin 21		5
Bin 21 to bin 22		5

TABLE 1. Bay Configurations for Example

Aisle Side	Left	Right
Number of bays	20	20
Distance between bay Center	30 inches	30 inches
Bay number	Bay Configuration	
1	I	I
2	I	I
3	I	I
4	I	I
5	I	I
6	I	I
7	I	I
8	I	I
9	I	I
10	I	I
11	II	II
12	II	II
13	II	II
14	II	II
15	II	II
16	II	II
17	II	II
18	II	II
19	II	II
20	II	II

TABLE 2. Aisle Layout for Example

Crane Parameter	Direction	
	Horizontal	Vertical
High Velocity (ft/sec)	5.0	1.0
Acceleration (ft/sec^2)	1.3	1.0
Deceleration (ft/sec2)	1.3	1.0

Crane Delay	Time (sec.)
Position	6.0
Extract	10.0
Insert	11.0

TABLE 3a. Crane Parameters or Example.

Pick Type	Operator Times (min.)		
	Minimum	Most Likely	Maximum
Regular	1.0	1.5	2.0
Hot	0.5	1.0	1.5
Cycle Count	1.5	2.0	2.5
Restock	1.0	1.5	2.0

TABLE 3b. Operator Parameters for Example.

P&D Coordinate	Distance (inches)
X (Horizontal)	40
Y (Vertical)	27

TABLE 3c. P&D Parameters for Example.

Simulation Parameter	
Length of run	480 min.
Number of Replications	3

TABLE 3d. Simulation Parameters for Example.

Pick Type	Distribution of Demand (%)
Regular	80.0
Hot	5.0
Cycle Count	10.0
Restock	5.0
TOTAL	100.0

TABLE 4. Random Loading Operation Type Distribution for Example

A total of 1450 bin demand were generated to be used in the three replications of the simulation. Each demand was assigned a pick type based on the distribution given in Table 4. Table 5 gives the actual breakdown of the demands used in each simulation run. Even though there are variations from the desired distribution, they appear insignificant.

RUN NO.	Number (%) of Picks by Type			
	Regular	Hot	Cycle Count	Restock
1	309 (80.1)	21 (5.4)	36 (9.3)	20 (5.2)
2	305 (79.2)	18 (4.7)	40 (10.4)	22 (5.7)
3	310 (81.4)	19 (5.0)	35 (9.2)	17 (4.5)
TOTAL	1166 (80.4)	71 (4.9)	75 (9.5)	138 (5.2)

TABLE 5. Operation Pick Type Distributions Actually Generated for Simulation.

Using the total picks for each run given in Table 5 and the fact that each run was for 480 minutes, one can quickly calculate average picks per hour as:

$$\frac{386 + 385 + 381}{3(480)/60} = 48 \text{ picks/hour}$$

The balance of the statistical data for the three replications is given in Table 6. The 98.24 percent crane utilization might cause one to feel that the performance of the miniload is dictated by the crane. This is not totally true as can be seen by comparing the crane cycle time (1.195 min.) with the cycle time (1.245 min.). The latter, which includes operator interference, yields 48 picks/hour while the crane is capable of 50.2 picks/hour.

Data Item	Run 1	Run 2	Run 3	Avg.
Average Crane Cycle Time (min.)	1.184	1.195	1.205	1.195
Average Cycle Time (min.)	1.240	1.241	1.253	1.245
Average Crane Travel Time: P&D to Aisle (min.)	0.220	0.223	0.227	0.223
Average Crane Travel Time: In Aisle (min.)	0.121	0.123	0.126	0.124
Average Crane Travel Time: Aisle to P&D (min.)	0.153	0.156	0.160	0.156
Average Crane Travel Time Per Move (min.)	0.165	0.167	0.171	0.168
Crane Utilization (%)	98.06	98.39	98.28	98.24
Operator Utilization (%)	78.06	78.61	77.98	78.22

TABLE 6. Summary of Statistical Data for Example.

The same geometry data and crane parameters were used to simulate a zoned system with 3 zones. Data on the zones is contained in Table 7. The desired distribution of operation types is shown in Table 4 and is the same for each zone. Because the closer bins have a proportionately higher percentage of demands, the throughput of the system should improve.

Zone	Percent of Bins	Percent of Demand
1	20	75
2	30	15
3	50	10

Table 7. Zone Data for Example

The zoned system achieved a throughput of 52.5 picks per hour, an increase of 4.5 picks per hour. The crane capacity (assuming no operator interference) increased from 50.2 to 56.9 picks per hour. Thus, the effect of zoning was somewhat lessened because of operator interference.

Table 8 summarizes the results for the 3 zone system. Note that the average crane travel time for each move has decreased, resulting in increased throughput. The crane utilization decreased while the operator utilization increased providing another indication of increasing operator interference. Increasing the number of zones in this system will result in diminishing returns as the operator time becomes a constraining factor on the performance of the system. In the next section, the operator pick time will be decreased, making the crane the constraining factor, so that the effect of zoning can be more clearly seen.

Data Item	Run 1	Run 2	Run 3	Avg.
Average Crane Cycle Time (min.)	1.055	1.053	1.055	1.054
Average Cycle Time (min.)	1.141	1.140	1.133	1.138
Average Crane Travel Time: P&D to Aisle (min.)	0.169	0.168	0.167	0.168
Average Crane Travel Time: In Aisle (min.)	0.096	0.095	0.093	0.095
Average Crane Travel Time: Aisle to P&D (min.)	0.103	0.101	0.100	0.101
Average Crane Travel Time Per Move (min.)	0.123	0.122	0.120	0.122
Crane Utilization (%)	95.69	95.53	95.01	95.41
Operator Utilization (%)	84.67	84.72	86.27	85.22

TABLE 8. Summary of Statistics for Example with Zones.

5. RESULTS FOR ZONED STORAGE

To investigate the effect of zoned storage on the performance of the system, the operator pick time was reduced until it was not a constraint on performance, and hot picks were eliminated from the model. Three runs each were made with random loading and with 3 to 9 zones. Data on the percentage of bins and demands for each zone is shown in Table 9.

		Number of Zones						
Zone	Percent of:	3	4	5	6	7	8	9
1	Bins	20	10	5	5	5	5	3
	Demand	75	50	30	30	30	30	20
2	Bins	30	10	5	5	5	5	3
	Demand	15	25	20	20	20	20	15
3	Bins	50	30	10	10	5	5	4
	Demand	10	15	25	25	15	15	15
4	Bins		50	30	30	5	5	5
	Demand		10	15	15	10	10	15
5	Bins			50	25	30	15	5
	Demand			10	6	15	8	10
6	Bins				25	25	15	5
	Demand				4	6	7	8
7	Bins					25	25	15
	Demand					4	6	7
8	Bins						25	25
	Demand						4	6
9	Bins							25
	Demand							4

Table 9. Distribution of Bins and Demand by Zone.

The 3 zone system uses the same percentages as the previous example. The 4 zone system is created by dividing zone 1 of the 3 zone system into 2 parts. The 5 zone system splits the first zone from the 4 zone system. The last zone of the 5 zone system is divided to create a 6 zone system, followed by splitting zones 3 and then 5 of the previous system to create a 7 and 8 zone model. The last zoning is created by rearranging the first 3 zones of the 8 zone system.

The throughput, in picks per hour, for the zoned and random system is shown in Table 10. It can be seen that moving from a random system to a system with three zones caused a definite increase in throughput for the system. After this point, creating additional zones had essentially no effect on throughput. These throughput results are based on a crane utilization of 100 percent, with no interference from the operator.

Zones	Run 1	Run 2	Run 3	Average
Random	49.6	49.6	49.5	49.6
3	55.5	55.8	56.0	55.8
4	55.6	55.5	55.9	55.7
5	56.2	55.2	56.9	56.1
6	56.0	56.0	56.6	56.2
7	55.8	55.5	57.1	56.1
8	56.2	56.2	55.9	56.1
9	56.5	56.8	56.1	56.5

Table 10. Throughput for Random and Zoned Storage

6. CONCLUSIONS

Simulation of a miniload system requries a great deal of input data. A front-end series of programs can greatly reduce data input problems while providing a method to store partial system descriptions for future use. Such programs can also simplify the process of experimenting with class based or zoned storage, as well as operation times and crane parameters.

A model of a single aisle LRC miniload system was used to investigate the effects of storing material based on anticipated demand. Moving from a random system to one with three classes resulted in an improvement in system throughput, measured in picks per hour. The addition of classes beyond 3 had a negligible effect on throughput. Up to 9 classes were used. The extreme of a class based system is velocity loading, where pans are stored based on relative frequency of picks. The performance of zoning in the example studied leads one to question the effectiveness of velocity loading a miniload. Further research is required to determine if velocity loading will outperform class-based assignment with a small number of classes.

7. REFERENCES

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