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# BISG Warehouse Benchmarking Study

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**Summary of Results for  
Data Collected through January 2006  
for the Book Industry Study Group  
Internet-based Data Envelopment Analysis for  
Warehousing**

*iDEAs*



Book Industry Study Group

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## Executive Summary

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## Acknowledgements

The work reported here is the result of an ongoing collaborative project between the Book Industry Study Group and the Keck Virtual Factory Laboratory in the School of Industrial and Systems Engineering at Georgia Tech. The Book Industry Study Group has provided access to their members for the purposes of data collection and financial support. However, this project would not have been possible without the prior work of the iDEAs-W project which benefited from the generous support of a number of organizations. The W. M. Keck Foundation is the founding sponsor of the Keck Virtual Factory Lab, and provided both financial support and computing facilities for this work. The Material Handling Industries of America (MHIA) has supported this work through a variety of promotional efforts, including providing booth space at both ProMat and the North American Material Handling Show, and travel support for the iDEAs-W team to both events. The Progress Group has given generously of their professional expertise in many discussions with the iDEAs-W team regarding performance assessment. The Logistics Institute at Georgia Tech has provided some release time and graduate student support through a grant from the Progress Group. Finally, the members of the Distribution Executives Interest Group have been very generous with their time and input to the project.

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## Accessing BISG iDEAs-W

BISG iDEAs-W may be accessed through the following url:

<http://www.isye.gatech.edu/bisg>

To obtain a password, contact the Executive Director of the BISG,

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## Contacting iDEAs-W team:

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# BISG Warehouse Benchmarking Study

The Book Industry Study Group (BISG) warehouse benchmarking study is a joint effort of the BISG and the Keck Virtual Factory Lab at the Georgia Institute of Technology. The project builds upon the Keck Lab's existing Internet-Based Data Envelopment Analysis System for system-based self-assessment of warehouses (iDEAs-W), a tool developed to help warehouse managers understand and benchmark the performance of their warehouses. The iDEAs tool is a free service provided by Georgia Tech, and is accessed by pointing a browser to <http://www2.isye.gatech.edu/ideas/>. The tool is based on a generic performance model of warehousing developed by Hackman *et al.* (2001) and produces a system efficiency score considering several warehouse resources and several warehouse services. The tool uses a mathematical technique called data envelopment analysis to determine a relative efficiency by comparing a single warehouse to the best possible performance estimated from a set of peer warehouses. Users can choose to be compared to all warehouses, to warehouses in a particular industry or to warehouses using a particular picking mode.

The Penguin Group was a user of the iDEAs-W tool and was interested in a book industry specific comparison. However, the iDEAs database did not include enough book industry warehouses to make this comparison possible. Thus discussions began between the Penguin Group and the iDEAs team to determine how a book industry specific comparison could be done. The project began in early 2004 when members of the iDEAs team visited Pittston, PA and Commerce, GA to see book industry warehouses and to begin to understand the special issues related to the book industry. A workshop was held to identify metrics and attributes which characterized the book industry. The iDEAs team constructed and proposed a model which was accepted by BISG. Based on this model a separate BISG benchmarking website was developed and launched in July of 2004. BISG worked to recruit participants over the next year and a half. As of January 2006 there were 25 warehouses in the database with data submitted for the basic model.

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**Deleted:** an ongoing project resulting from a series of actions. To summarize briefly, the tools used in the BISG study are based on the

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**Deleted:** quantify how efficiently inputs are used to generate outputs; the computations are performed using a Georgia Tech server and the results provided almost instantaneously. A user receives results quantifying the performance of their warehouse along with some benchmarking information.

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This report summarizes the results of analyzing these 25 BISG warehouses. The results will be described in the following nine sections:

- Characterizing the warehouses
- Warehouse customers and services
- Warehouse activity
- Warehouse operations
- Warehouse information handling
- Warehouse workforce
- Warehouse internal perspective
- Performance analysis
- Conclusions

The results in this report measure efficiency and search for practices and attributes associated with high efficiency among the 25 warehouses. The model and metrics used are described in the Performance analysis section. Also, at the end of this document there is a glossary with the definition of the terms to be used.

Not all the twenty-five warehouses answered every question. Because the sample size is small to begin with, the presence or absence of a few data points can influence the results from a particular analysis. Thus, industry-level analysis of the data often yields results that are not statistically significant. Nevertheless, there are some interesting industry-level conclusions. In addition each warehouse participating in the study received an analysis of their specific performance and major conclusions that could be drawn from their data.

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# Characterizing the warehouses

On January 31<sup>st</sup> 2006, there were 25 BISG warehouses that had complete input and output data. While all warehouses in this set service customers related to the book industry, there are significant differences among these 25 warehouses. The warehouses can be classified in two main categories: distribution and publishing. In this set 70% are distribution warehouses and 30% are publishing warehouses. This is just one characteristic of these warehouses. In the following section we will explore the similarities and differences.

Warehouses that have been in the same facility for a longer period of time have had time to learn how best to operate in that facility. However, if the equipment and practices of the warehouse are not updated over time, the use of outdated processes may lead to inefficiency. On average, a book industry warehouse has been in the same location for a period of 14.5 years. About 15% of these warehouses have been in the same location for more than 25 years and ~50% for less than 10 years. The chart in Figure 1 shows the distribution of the time the warehouse has been at the same location<sup>1</sup>.

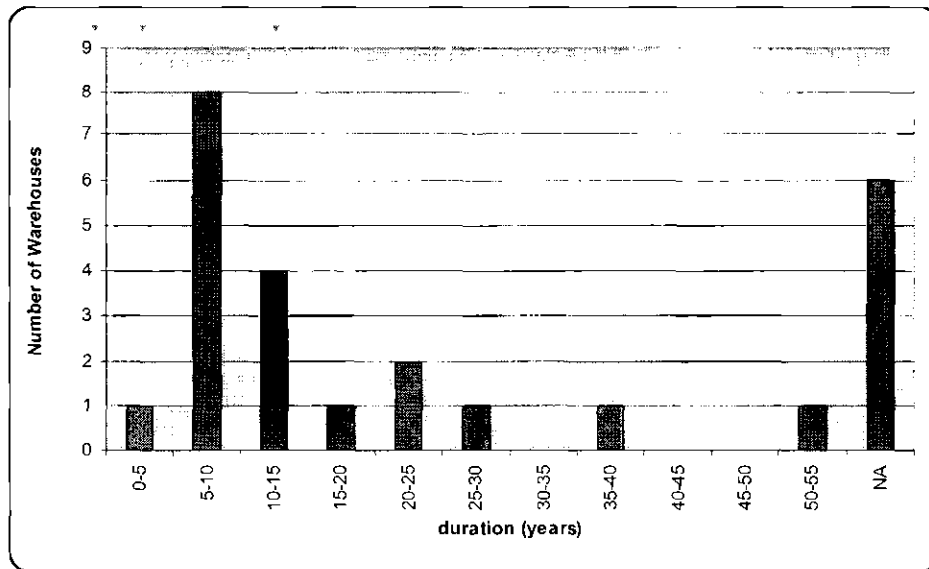


Figure 1. Time the warehouse has been at the same location

<sup>1</sup> For all charts, the data labeled "NA" represents warehouses that did not provide data.

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Each warehouse in this group handles books, but many handle other products as well. The wider the variety of products, the more difficult material handling becomes. Figure 2 shows different products and the number of warehouses handling each product type. The 42 responses from 25 warehouses indicate that most warehouses handle more than one type of product.

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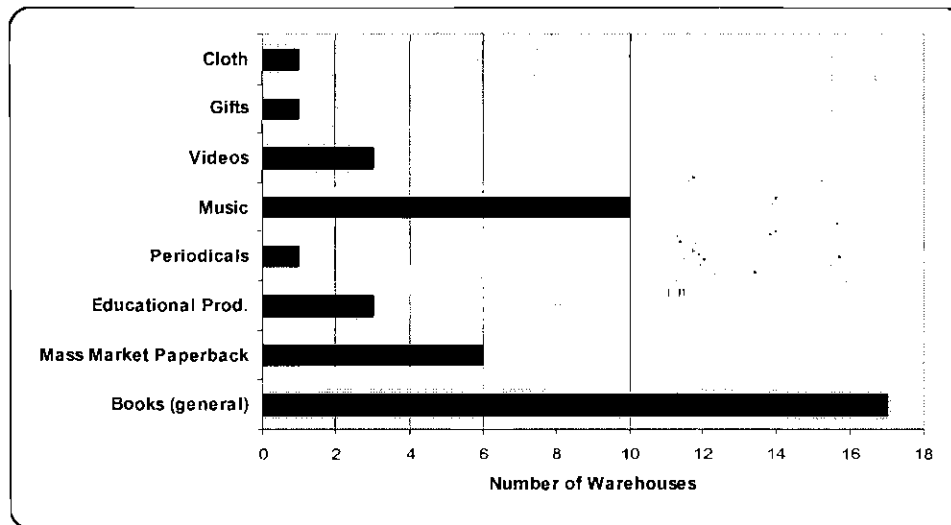


Figure 2 Product Type Distribution

All other things being equal, handling a wider variety of products will require more resources and cause a warehouse to appear less efficient than a warehouse that only handles a single product. There are correlations between the types of products distributed by the warehouses. For example 53% of the warehouses that distribute books (hardcover, textbooks, etc.) also distribute music products. Similarly, 25% of the warehouses that distribute general books and mass market paperbacks also distribute educational products. These correlation statistics are shown in Table 1.

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Table 1.

Product Types	%
Books (general) & Mass Paperback	24%
Books (general) & Educational Products	6%
Books (general) - Mass Paperback & Educational Products	25%
Books (general) & Music	53%
Educational Products only	33%
Music & Mass Paperback	20%
Music & Educational Products	10%

The size of a warehouse is important because larger warehouses process more orders and allow overhead costs to be distributed over a greater output, reducing the overhead cost per unit. However, as a warehouse becomes too large, organization of such a large number of people and resources becomes difficult, which may result in decreased efficiency. This makes size an interesting characteristic of warehouses to investigate. Most of the warehouses in the BISG data set (80%) are smaller than 450,000 sq. ft. in area, with an average of about 330,000 sq. ft. The size distribution of the warehouses is shown in Figure 3.

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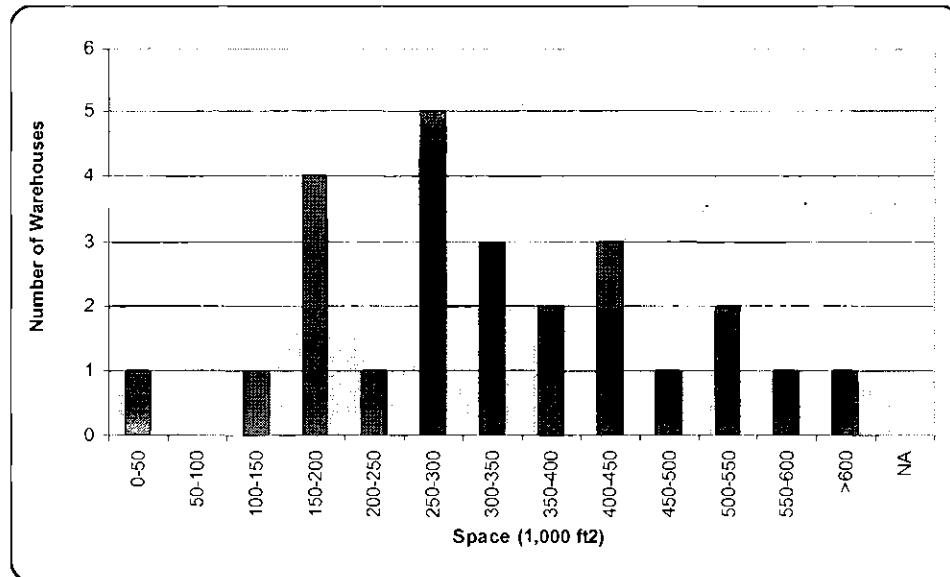


Figure 3. Distribution of Warehouses by Size

Another resource that can be used to quantify the warehouse size is the amount of labor. Here, labor hours include both direct and indirect labor. Over 80% of the warehouses use less than 350,000 labor hours per year (or equivalent to 175 full time

workers), and the other ~20% of the warehouses use greater than 500,000 labor hours per year (or about 250 workers). Two groups of warehouses in terms of labor hours used can be identified. This is shown by Figure 4. Both groups have nearly the same labor productivity measure (lines/labor hour). The warehouses with less than 350,000 hours/year have an average productivity of 19.78 lines/hour, and the other group has an average of 19.12 lines/hour. On the other hand, the group using more labor has on average a considerably faster inventory turnover! While the first group's average inventory turnover is ~2.6, the second group's average turnover is 4.0.

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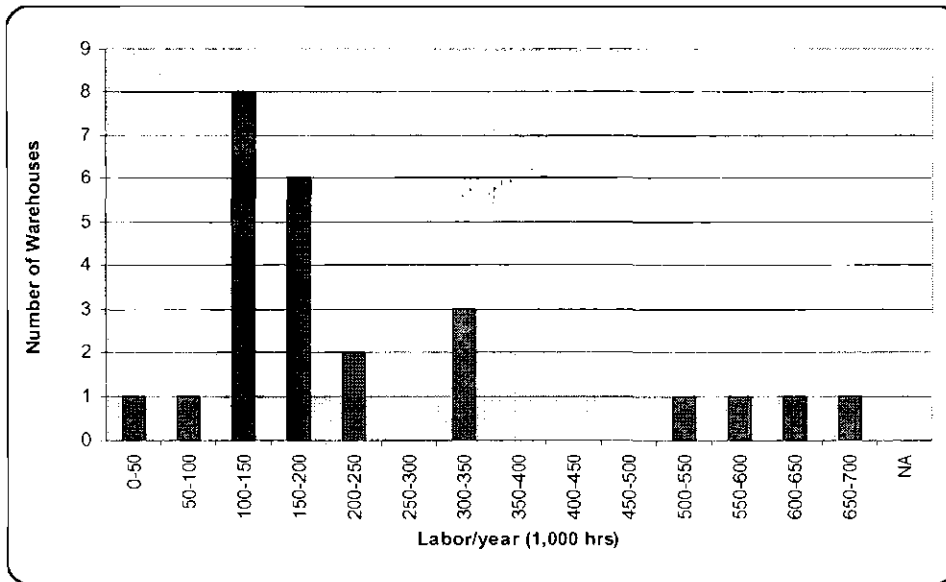


Figure 4. Distribution of Warehouses by Labor

Labor and space are highly positively correlated, as might be expected. Larger spaces require longer traveling times between warehouse locations and also imply more activity inside the warehouse. The average ratio of labor/space for these book warehouses is 0.73 [hrs/sq.ft.], and the 95% confidence interval ranges from 0.56 and 0.9.

Another important resource used by warehouses is equipment. In this study an inventory of equipment is collected for each warehouse and a standard cost is assigned to each equipment type allowing equipment to be aggregated to a single “standardized” investment input. Over 90% of the warehouses have an investment less than \$4 million. There is a great variability in the amount invested in these warehouses; the range of investment from smallest to largest is more than \$10 million. Figure 5 shows the investment distribution for these BISG warehouses.

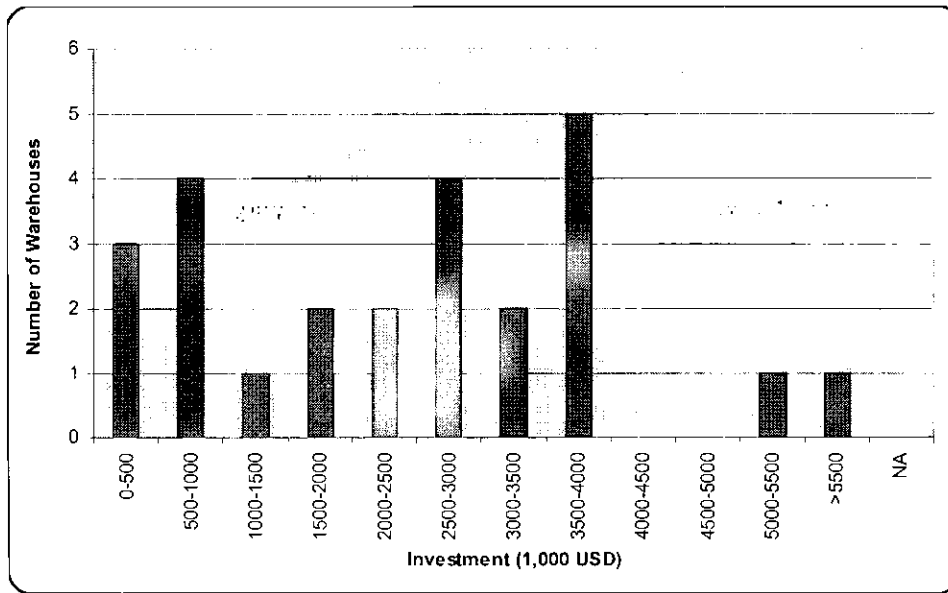


Figure 5. Distribution of Warehouses by Equipment Investment

The distributions of space, labor and investment are not identical, in other words, each warehouse uses a different mix of resources.

Also, the average ratio of investment/space is 7.5 (USD per sq. ft), and 95% of all warehouses observed are within the range of 5.6 and 9.4. Investment and space are positively correlated.

The ratio between labor and investment among the warehouses has a 95% chance of being between 0.08 and 0.22 (labor hour per \$ of equipment). The average for this sample of warehouses is ~0.15 labor hour per \$ of equipment. Labor and investment are positively correlated as can be seen in Figure 6. This correlation is statistically significant. However, the data also show that investment and labor/investment ratio have a negative statistically significant correlation. That means that while it is expected for labor to increase if the investment increases, the rate of increase diminishes as the investment increases to higher levels. In other words, as more equipment is used, the proportion of labor used declines, as might be expected.

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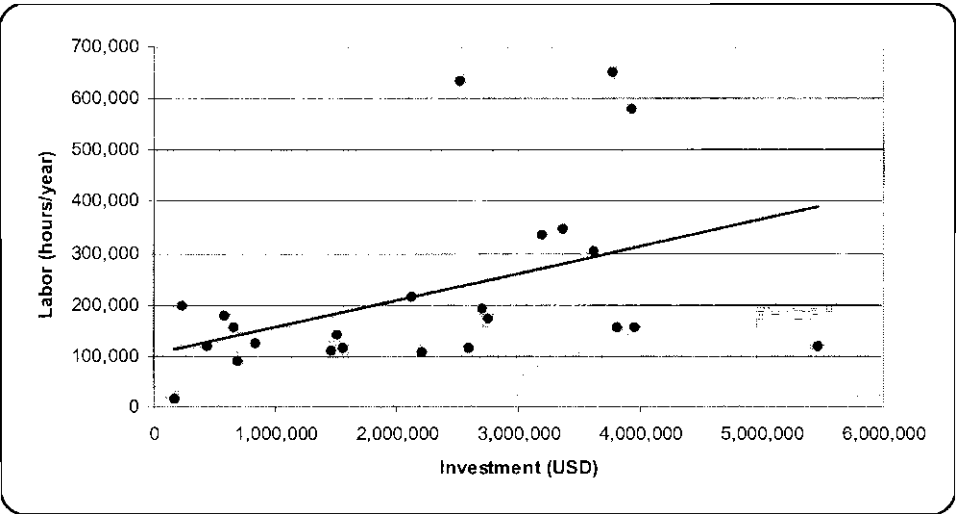


Figure 6. Labor vs. Investment

## Warehouses customers and services

The types of customers and the requirements of those customers drive the activities performed and the level of resources consumed in a warehouse. We would like to understand, if possible, how these characteristics of warehouses are reflected in their relative efficiencies.

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The customers fall into three basic categories wholesalers, retailers, and individuals. Figure 7 shows the frequency of certain customer types in the responses of the book industry warehouses. The 49 responses from 25 warehouses indicate that, on the average, BISG warehouses serve 2 distinct types of customers.

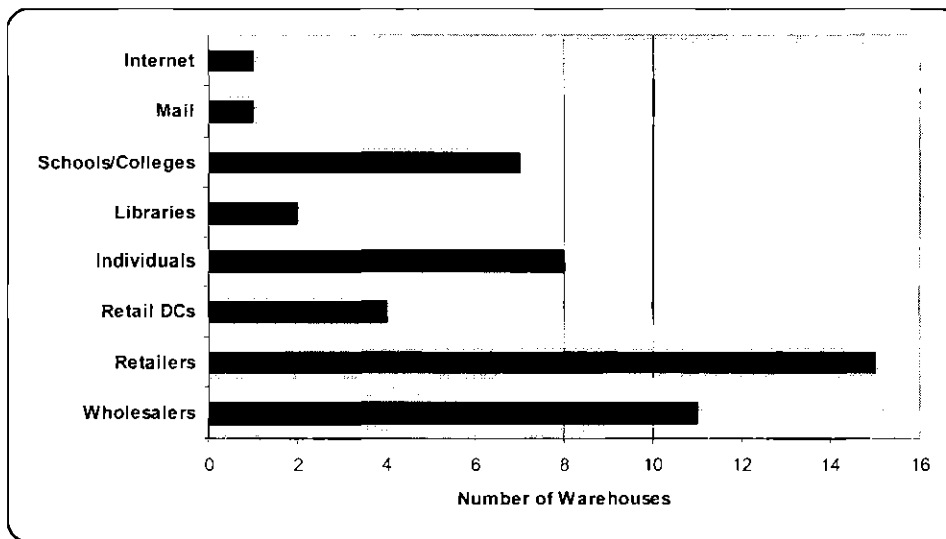


Figure 7. Distribution of customer types in warehouses

There are correlations between the types of customers served by the warehouses. For example 100% of the warehouses that serve wholesalers also distribute to retailers. On the contrary, only 73% of the warehouses that serve retailers also serve wholesalers. Serving a variety of customers with their different needs tends to reduce the ability of the warehouse to specialize and thus tends to increase the resource usage. The correlations between customer types are shown in Table 2.

Table 2. Percent of warehouses serving the customer type that also serve the second customer type

Customers	%
Individuals & Retail DCs	38%
Individuals & Schools/Colleges	63%
Retailers & Retailers DCs	27%
Retailers & Wholesalers	73%
Wholesalers & Retailers	100%
Wholesalers - Retailers & Individuals	45%
Wholesalers - Retailers & Schools/Colleges	27%

The mix of the types of customers served affects the operation of the warehouse (e.g. broken case vs. full case, number of items per title per order, average volume of an order, etc.) These warehouses also could be divided in clusters, depending on the main types of customers that they serve. Figure 8 shows three main subgroups for these warehouses.

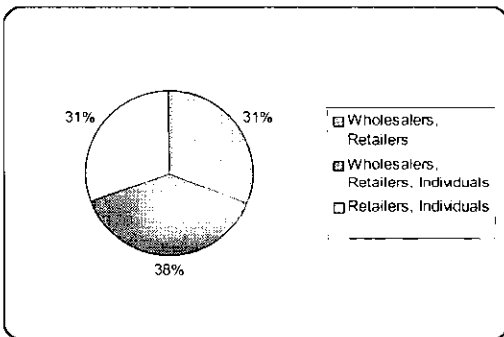


Figure 8. Clusters by customer type mix

Even if the customers are similar for a warehouse, having many different customers of the same type can also add diversity to the demand patterns. One measure of the number of different customers is the number of ship-to locations. The BISG warehouses have a large number of ship-to locations. According to the information given, about 40% of these BISG warehouses have fewer than 50,000 shipping locations and over 20% have more than 900,000 shipping locations. In fact, the smallest number reported for this category was 8,000 locations.

For shipping consolidation, 53% of the warehouses consolidate based on the freight carrier, 33% based on the geographic region, and 14% consolidate single orders.

Even though customer requirements are often diverse, warehouses tend to process orders in a similar way. For example, typically a warehouse has a fixed response time for all orders, allowing all orders to be processed in a standard way and avoiding the need for

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individual attention for particular orders. However, for the book industry, response time differs between the warehouses. Figure 9 shows the distribution of the response time for these warehouses. The majority (57%) has a response time of one or two days. The number of orders fulfilled meeting the response time is 96% on average.

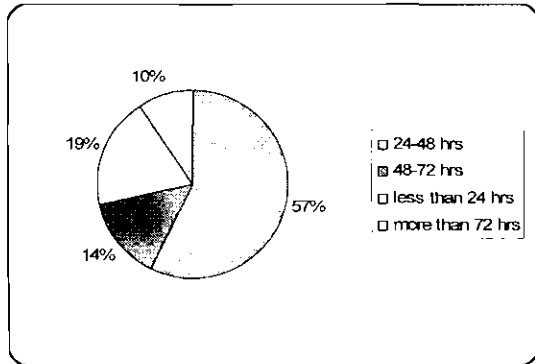


Figure 9. Response Time Distribution

Many of the practices of the warehouses are related to customer service, as shown in Table 3. These book industry warehouses offer a variety of services that are highly customer-oriented. For example, half of the warehouses dedicate more than 20,000 labor hours to value added activities. The average pack and hold duration ranges from one to two weeks for ~55% of the warehouses, and for about half of the warehouses pack and hold orders represent from 70 to 100% of the total orders. For approximately 70% of warehouses the return process represents more than 10,000 labor hours (5 full time workers dedicated to return process).

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Table 3.

Customer Service Practices	%
Adjustments	57%
Advance notice	80%
Billing info with order	62%
Product info with order	62%
Compliant shipping	95%
Labeling	71%
Pack and hold	48%
Return Process	67%



## Warehouses characteristics and activities

The characteristics distinguish one warehouse from another, and warehouse activities use resources to meet customer requirements.

One important characteristic is inventory turns. In this study, inventory turnover is on average equal to approximately 3 per year, or about 120 days of inventory on hand. About 90% of the warehouses have an inventory turnover less than 5 per year. The complete distribution is shown in Figure 10. The two warehouse turning inventory the fastest in Figure 10 have a higher ratio of lines/hour than the rest of the warehouses.

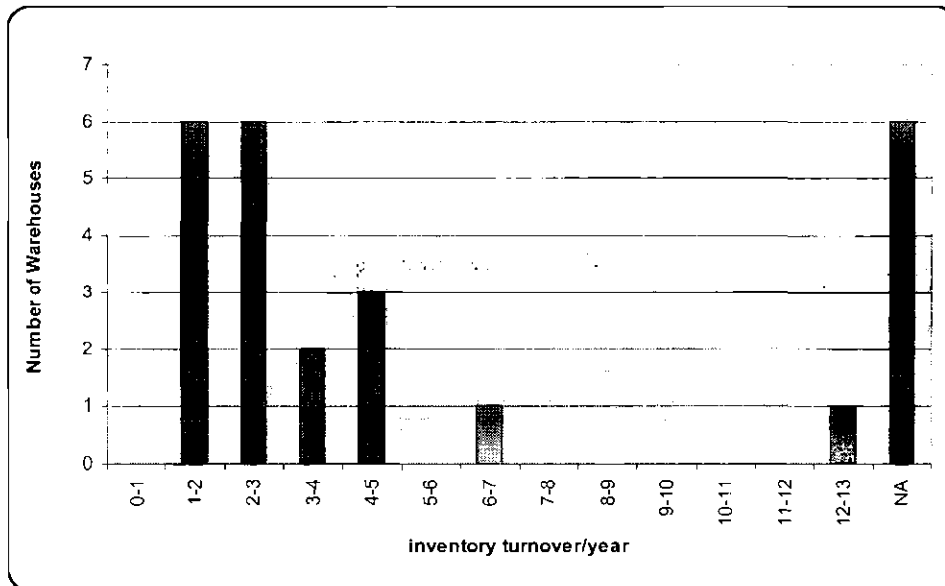


Figure 10. Inventory Turnover Distribution

The activity level of the warehouse can vary throughout the year due to seasonality of demand. It is important to characterize this seasonality because warehouse resources are not completely flexible, making it neither possible nor practical to adjust all resources levels downward during low demand seasons. The average seasonality index is 1.6. Approximately 75% of the warehouses have seasonality between 1 and 2. The complete seasonality distribution is shown in Figure 11.

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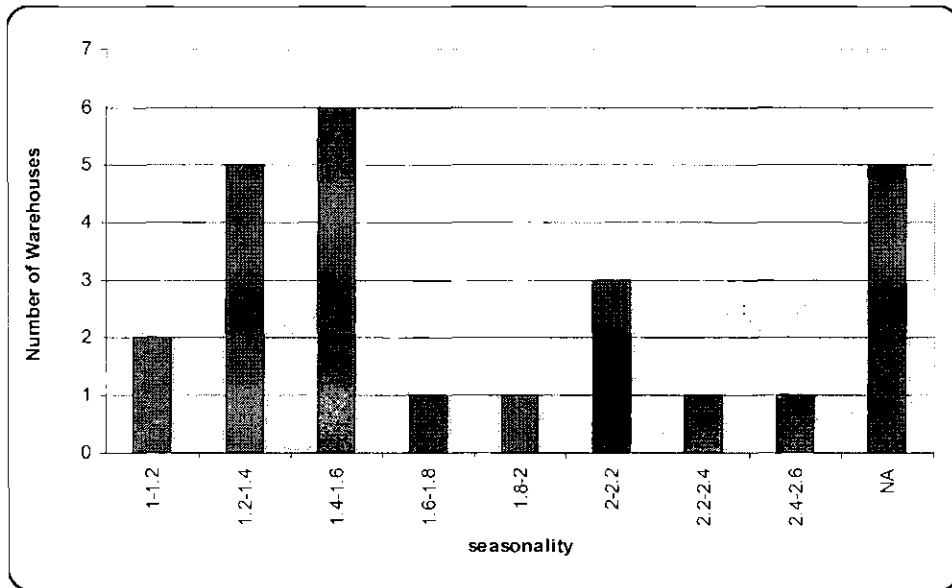


Figure 11 Seasonality Distribution

Order lines may require goods in broken cases (*pieces*), full cases, or pallets. The demand that the book industry warehouses face consists of all three. On average ~80% of picked lines are broken case lines. About 70% of these BISG warehouses pick between 1 and 5 million broken case lines. The complete distribution of broken case lines as a percentage of total lines is shown in Figure 12.

There is a positive correlation between the quantity of broken case lines and the labor used. This is not surprising because the nature of broken case picking is generally more labor intensive. Moreover, the increase in broken case lines quantity is positively correlated with the increase in the labor and space ratio (i.e. more labor is done in a smaller area).

Among BISG warehouses, about 70% processed between 100,000 and 1.2 million full case lines, and 15% picked less than 100,000 full case lines. About 65% of warehouses picked less than 10,000 thousand pallet lines, and about 15% picked more 50,000 pallet lines. The pallet lines quantity, for this sample, is correlated positively with the inventory turnover, items per title, order average volume and weight. When a warehouse has a pallet as a major handling unit, the orders tend to be bigger and inventory turns over more quickly.

It is also relevant to mention that on average 5.6% of the lines picked are rush lines.

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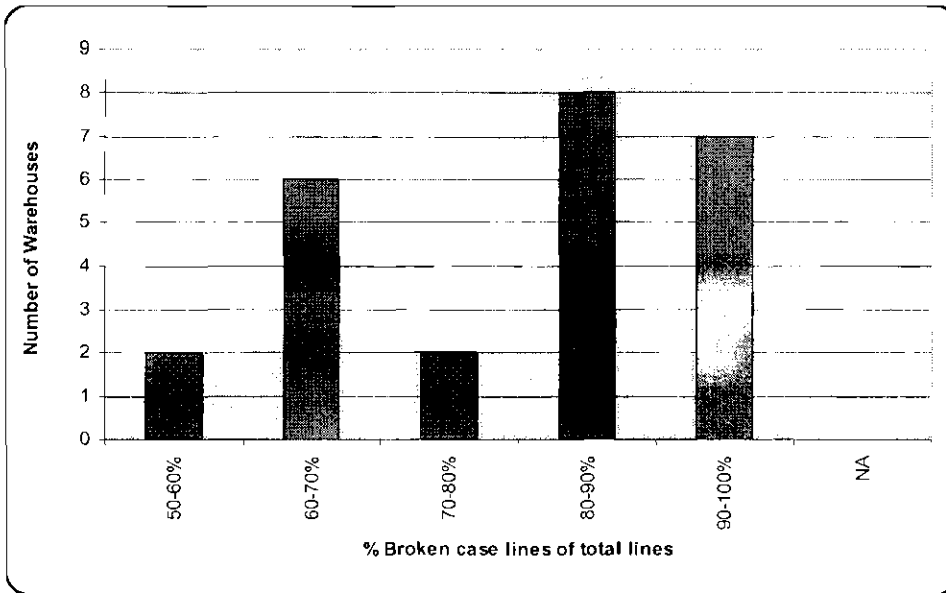


Figure 12. Percentage of Broken Case Lines

A traditional metric in warehousing is total lines picked per labor hour. Figure 13 shows that about 80% of the warehouses have a pick rate between 10 and 25 picks per labor hour. The average is 19 lines per hour. However, according to the given data and as shown in Figure 13, there is one warehouse with a rate of 55 picks per hour. Note that total lines include the sum of broken, full and pallet lines. Labor includes the direct and indirect labor, not just order picking labor.

The warehouses with 35 or more lines/hour, shown in Figure 13, both have on average a very high percentage of broken case lines (~98%). On the other hand, the warehouse with fewest lines (less than 5 lines/hour), has a very high labor/investment ratio, so this warehouse seems to be in terms of labor, a relatively low investment warehouse.

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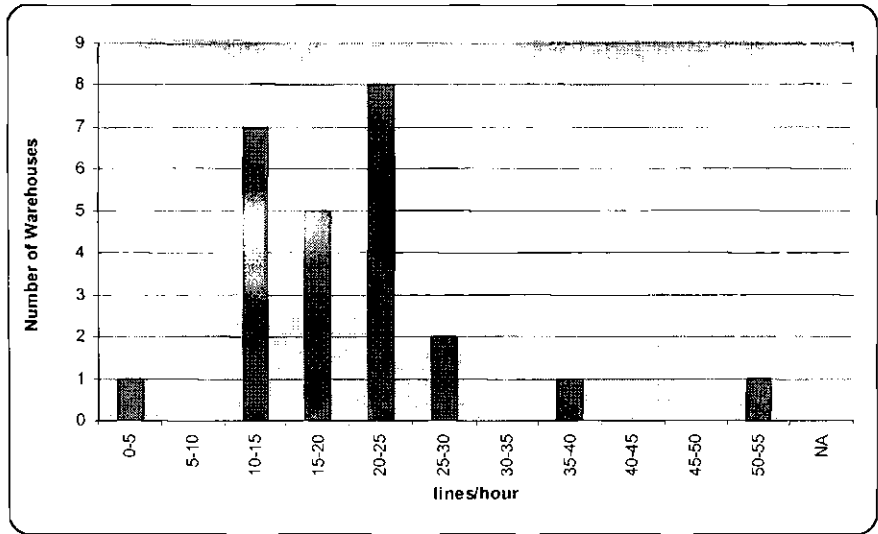


Figure 13. Lines picked per labor hour

Typically the number of lines processed in a warehouse receives more attention than the number of orders. However, the number of orders is also an important measure of the work done by the warehouse. The average number of orders processed per year is 750,000 for these warehouses and approximately 20% of the warehouses have more than 1 million total orders per year. Figure 14 shows the distribution of total orders. On average there are 6.21 titles per order, and about 90% of the warehouses have an average of 10 or fewer titles per order. On average about 7% of the orders are rush orders, but 20% of the warehouses claimed a rush order percentage greater than 15%. The number of rush orders is an indication of the percentage of orders that do not follow the standard product flow of the warehouse. These orders typically cause disruption and are filled less efficiently.

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The physical dimension of the orders varies greatly across the book industry. The average volume of each order is less than 5 ft<sup>3</sup> in about 75% of the warehouses; however, there are several warehouses that reported an average order volume greater than 60 ft<sup>3</sup>. The average weight per order ranges from 10 lb to 150 lb in about 80% of these book warehouses. About 55% of the warehouses have an average weight per order of 50 lb. or less. However, there is one warehouse that reported an average order weight over 4,000 lb.

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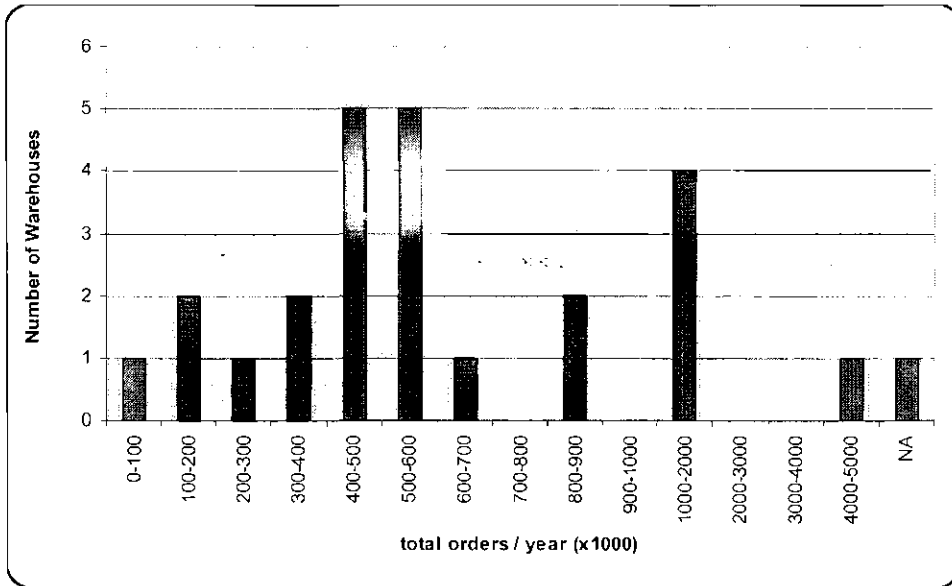


Figure 14. Distribution of Total Orders

While orders and characteristics of orders describe the work of the warehouse on the outbound side, replenishments characterize the flow of goods on the inbound side. Although time constraints on put-away are generally less severe than for order picking, the amount of labor required for this activity can be significant. About 70% of the warehouses have 50,000 or fewer replenishments per year. Figure 15 shows the distribution of the total number of replenishments. To have more than 10 million replenishments relative to a large SKU span (see below), the average individual SKU is replenished once a day, which means that there might be a misunderstanding of the concept of replenishments per SKU per year in some cases.

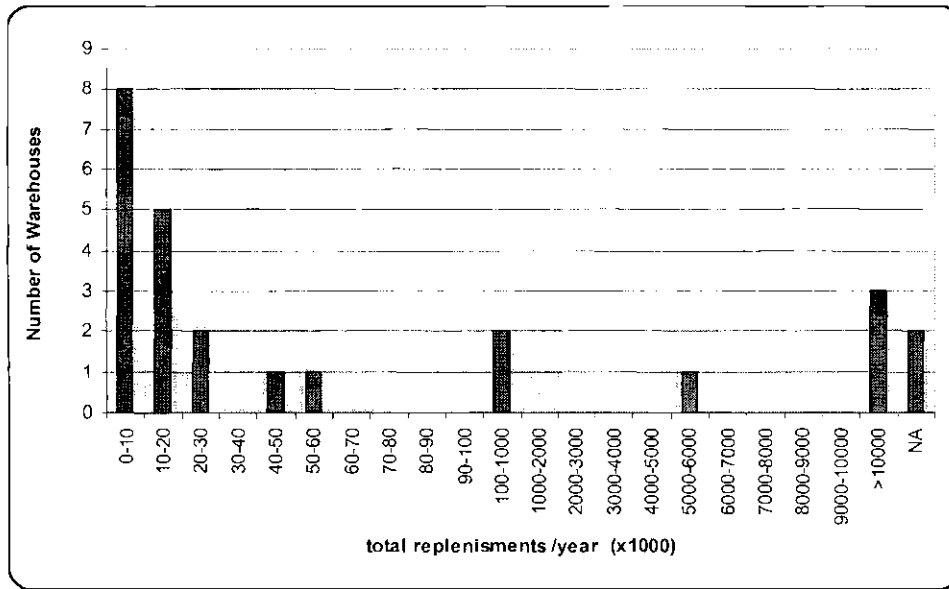


Figure 15 Total Replenishments

As can be seen in Figure 15, there are two main groups of warehouses in terms of total replenishments: warehouses with more than 100,000 replenishments per year, and warehouses with less than 60,000 replenishments. It was found that warehouses in the first group have on average a larger number of suppliers and a larger number of orders. Also, they are bigger in terms of labor and investment, but not considerably bigger in terms of space. This suggests that the number of replenishments is positively correlated with the number of suppliers and orders, and that a higher number of replenishments are to be expected in relative larger warehouses (in terms of labor and investment).

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The number of suppliers providing replenishments varies significantly between the different warehouses. Figure 16 shows the distribution of the number of suppliers. In this figure it can be observed that the BISG warehouses could be clustered in three groups according to the number of suppliers. Around 50% of the warehouses have fewer than 40 suppliers, and approximately 20% have 100 or more suppliers. Labor hours and the number of suppliers are positively and significantly correlated.

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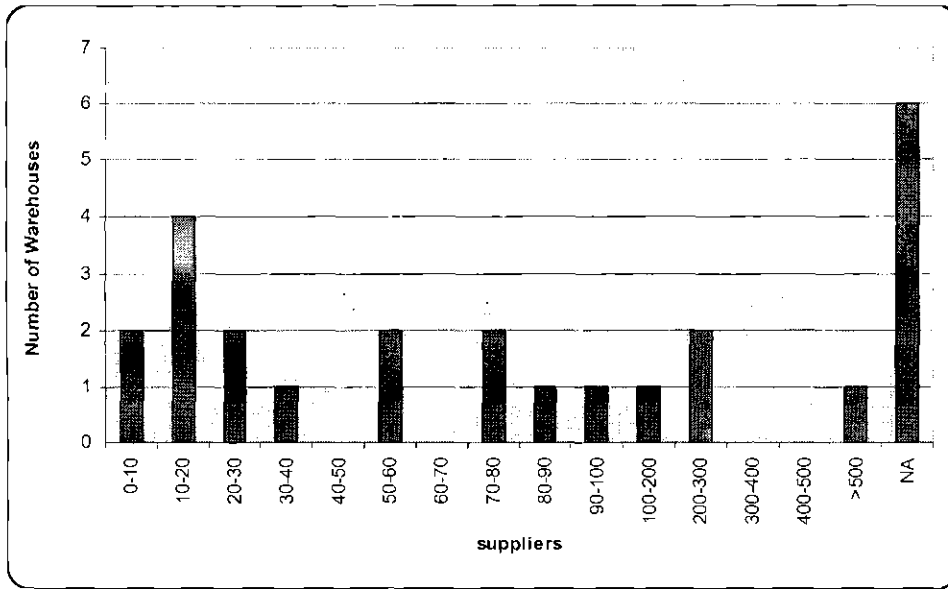


Figure 16. Number of Suppliers Distribution

The number of active SKUs in the warehouses varies greatly. About 60% of the warehouses have a SKU span of 20,000 SKUs or less. The rest of the warehouses have a SKU span between 20,000 and 50,000 SKUs. One warehouse reported a span greater than 50,000 SKUs. Figure 17 shows the total SKUs distribution. It was observed that warehouses in the highest percentiles of the SKU span were also in the highest percentiles of the number of total replenishments. This is also true for SKU span and the number of suppliers. Also, it was found that in average distributor warehouse has a larger SKU span than the average publisher.

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Pareto's principle suggests that 80% of the activity of a warehouse is driven by 20% of the SKUs. From the total SKUs, the percentage of the SKUs that represents the 80% of the activity of the warehouses (in terms of number of lines shipped) is 20% or less for only 50% of the warehouses, and 40% or more for about 20% of the warehouses. When this Pareto's percentage gets closer to 80%, it suggests that there are not many 'fast movers', and practices like Velocity-Based Slotting may not be justified. On the other hand, the percentage of the total SKUs that make 80% of the total volume shipped lies between 10% and 25% for about half of the warehouses, and about 45% or more for the other half.

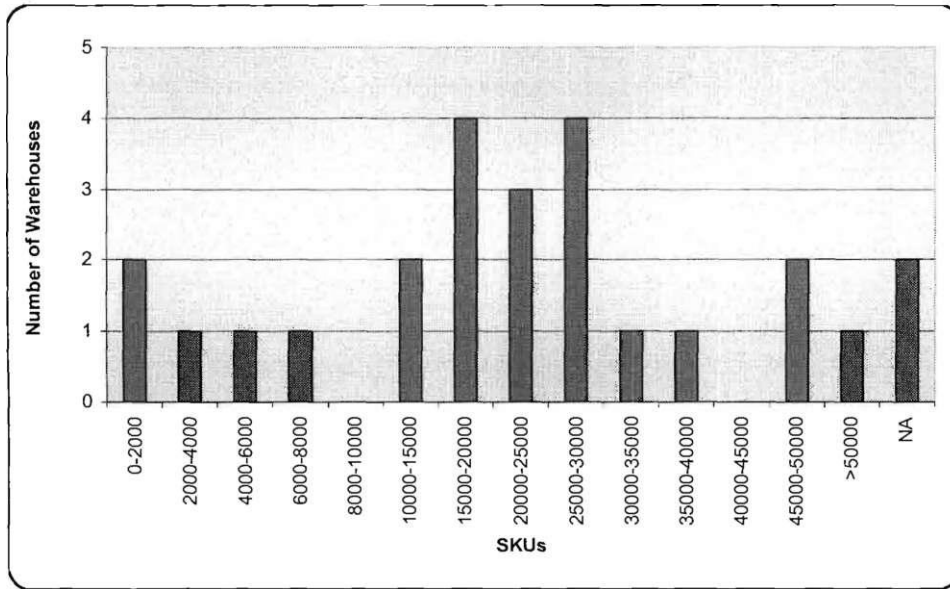


Figure 17 Total SKUs Distribution

Having a large number of active SKUs increases the complexity of the warehouse, but if the set of active SKUs is changing, this is a further complication. Over the total SKUs, the average percentage of SKU changing (SKU churn) is 24% of the total SKUs, and over 65% of the warehouses experience a SKU churn between 15% and 35%. This distribution is showed by Figure 18. Note that only 60% of the warehouses answered this question.

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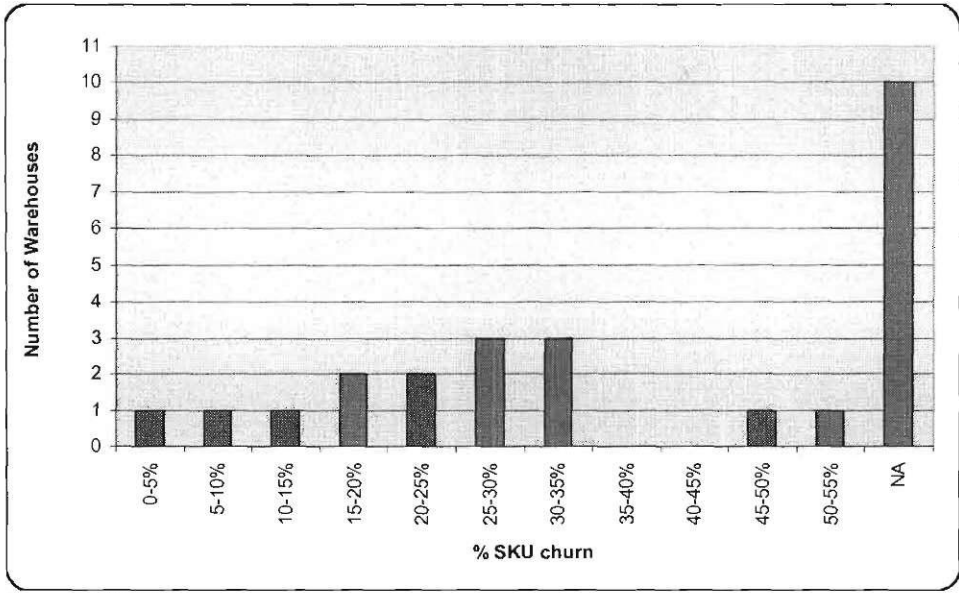


Figure 18. SKU Churn

## Warehouses operations

While the activities of the warehouse describe at a high level the characteristics of the demand and replenishment process, warehouse operations better describe the implementation issues. One characteristic of the operations of a warehouse is the space utilization. The average space utilization for the BISG warehouses is around 85%. This is shown by Figure 19. Approximately 90% of the slots available are occupied on average. Note also that ~40% did not answer the question about the space utilization.

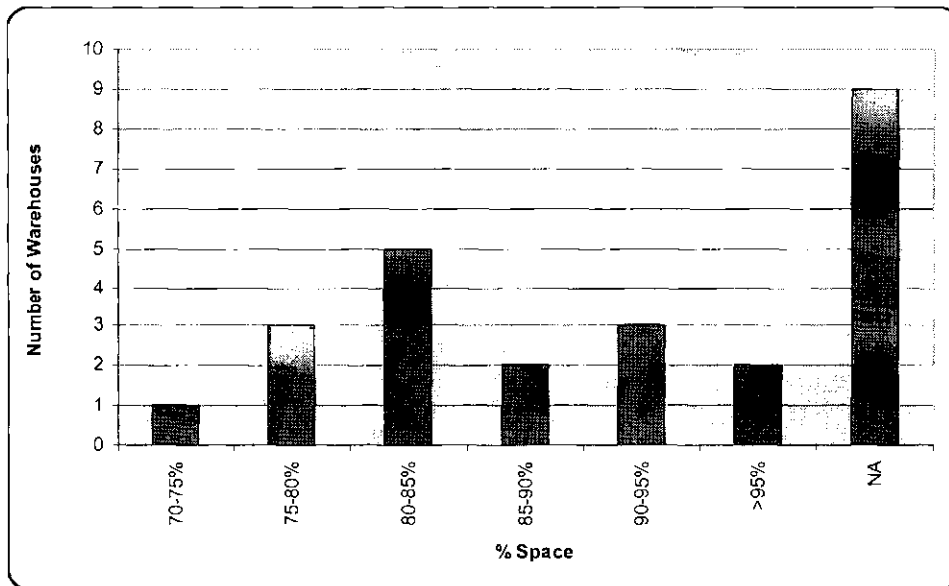


Figure 19. Distribution of Space Utilization

In the book industry the number of items per title describes the average inventory available to buffer against demand. About 50% of the warehouses have fewer than 10 units per title on average and ~20% more than 20 units per title. However, there is one warehouse of the group that has more than 150 units per title. Figure 20 shows the distribution of the number of units per title. The warehouses in the left of this figure (i.e. warehouses with fewer units per title) are relatively smaller warehouses (in terms of space) with a lower investment/space ratio than the average warehouse.

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The number of locations per title describes the complexity of the picking operation. About 55% of the warehouses average between 1 and 4 locations per title. The maximum average number of locations per title is 6 for these warehouses. The complete distribution of locations per title is shown in Figure 21.

The number of titles per location describes the balance of pick slots to the SKU span. An increase of titles per location is positively correlated with an increase in broken case lines, and, as might be expected, negatively correlated with the increase in full case lines. In general, these book warehouses have one title per location.

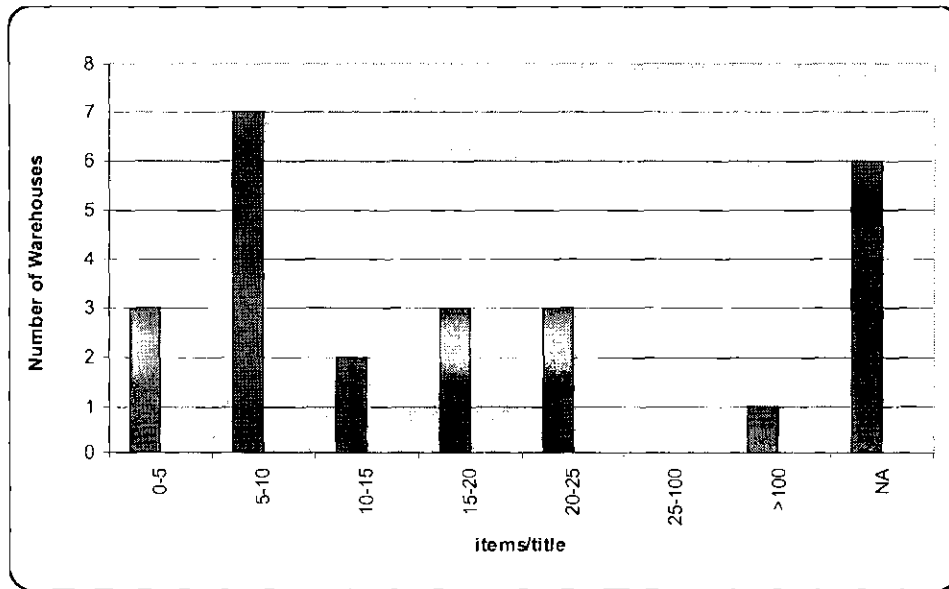


Figure 20. Units per Title

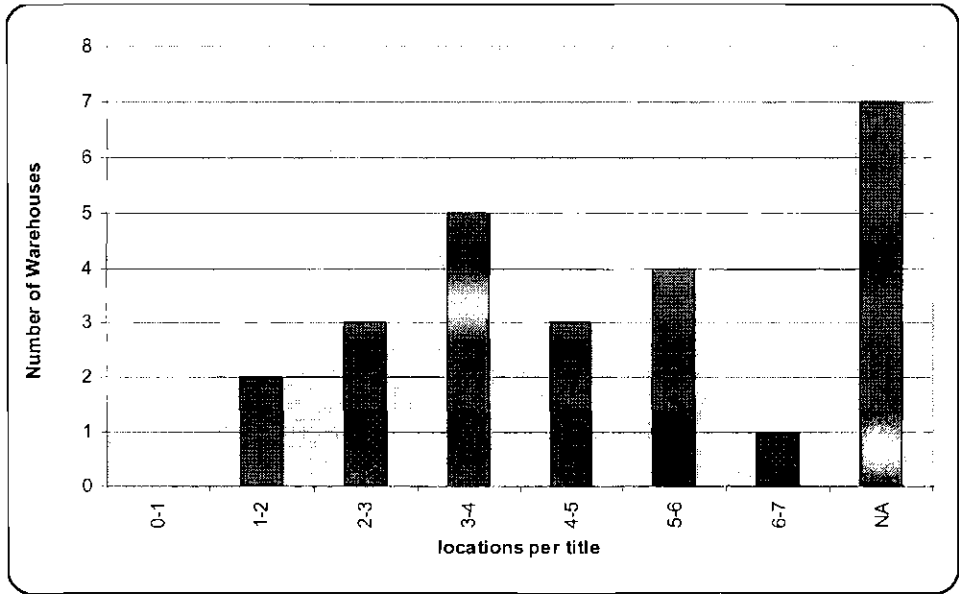


Figure 21 Locations per Title

To further describe the picking operation of the warehouses the number of zones was investigated. About 45% of the warehouses fewer than 10 pick zones, and in 15% of them there are more than 30 pick zones. Single orders are picked in 38% of the warehouses, and 62% of them batch orders for picking: 42% consolidated based on the carrier, 10% based on the arrival time, and 10% by geographic region. The planning horizon is less than a day for 52% of the warehouses, one to three days for 38%, and more than three days for 10%.

Another important aspect of warehouse operations is the amount of inventory on-hand. More inventory typically improves customer service, but increases the number of resources necessary to process and maintain that inventory. Figure 22 shows the on-hand inventory distribution for the BISG warehouses. About 70% of the warehouses have an on-hand inventory smaller than 30 million items. In terms of inventory value, about 50% of the warehouses have \$40 USD million or less as on-hand inventory and ~25% more than \$100 million.

**Comment:** Yes, inventory turns are discussed in the next section. We collected data about \$ of inventory so we are just discussing that data

**Comment:** do we have enough data to determine inventory in days of demand?

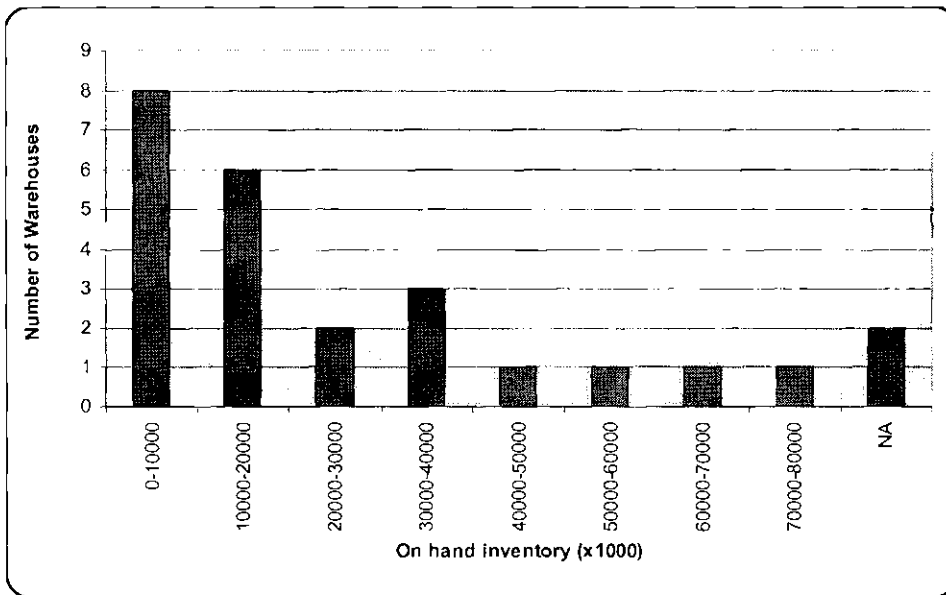


Figure 22. Inventory on Hand Distribution

On-hand inventory and on-hand USD are both positively correlated with space. Labor and investment are also good predictors of the size of the operation, but in this sample the correlation with the space is stronger.

In the long run, the flow of goods into the warehouse is equal to the flow of goods out of the warehouse. If this is not true, then inventory levels would be steadily growing or decreasing. This is the basis for Little's Law which can be interpreted in warehousing terms as saying

$$\text{Inventory Turns} = \frac{\text{Items Shipped}}{\text{Items in on-hand Inventory}}$$

This law can be used to check the consistency of the data provided by the warehouses. This calculation showed 75% of the time (or for 19 of the warehouses) the values reported were consistent. This is a measure of the quality of the data provided.

Within warehousing there are many specialized practices that can be implemented to improve warehouse operations. These practices increase the complexity of the operation, so the benefits need to be weighed against the challenges. Table 4 shows the percentage of warehouses that use certain practices in their operations. As can be seen in the table, automated sorting, is a widely used practice in these warehouses.

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Table 4.

Practices	%
Auto sortation	88%
Crossdock	50%
Task interleaving	40%
Pick to light	17%
Velocity-Based Slotting	50%

The increased complexity of these practices is handled by increasing the supervision within the warehouse. About 80% of the warehouses spend 15% or less of the budget on supervision. The average for this expense is approximately 11%. Similarly, close to 80% of the warehouses devote 15% or less of the budget in maintenance.

While the practices above are related to physical issues within the warehouse, there are also a variety of practices related to information technology. The information technology specific practices are discussed in the next section.

## Warehouses information handling

Information technology is not an attribute particular to a few technologically advanced warehouses; it is a common feature of the book warehouse. The difference concerning IT between warehouses is in how IT is used. Sometimes IT is used only to keep records and track of activities, but in the book industry it is also being used to support decision making. Table 5 shows that 100% of the warehouses use a WMS, but not all of them use the complete set of features that a WMS could offer.

Table 5.

IT	%
WMS	100%
WMS Replenishment	83%
WMS Strategy	100%
WMS Slotting	50%

The Manhattan Associates WMS is used by the 38% of the warehouses. The complete distribution of WMS providers is shown in Figure 23.

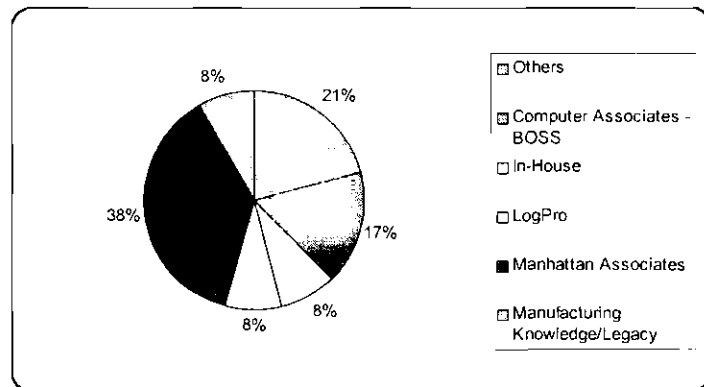


Figure 23. WMS Vender Distribution

The majority of the warehouses use radio frequency (rf) communication. The rfid technology is still new for these warehouses and not widely used. Table 6 shows the percentage of warehouses that use rf communication.

Table 6.

rf Communication	%
rf Putaway	75%
rf Retrieval	73%

Barcoding is a common practice among these warehouses. Barcoding of packages and items is used in about 90% of the warehouses. Locations are barcoded in around 88% of the warehouses. Approximately 80% of the warehouses have an inventory accuracy of 90-100%; however, there is one warehouse that reported accuracy below 40%.

Both the physical practices and the IT practices are important. While the organization of the warehouse is not the only issue, the quality of the labor in the warehouse is also important. This issue is addressed in the next section.



## Warehouses workforce

Labor is a critical resource for warehouse operation and one of the most important challenges for many warehouse managers. Figure 24 shows the distribution of labor turnover for the warehouses. About 70% of the warehouses reporting have a turnover less than 10%, and ~10% more than 40%. It's important to notice that there is one warehouse that claimed to have a turnover greater than 80%, which is considerably larger than the average (which is about 12%). Over a third of the warehouses did not report labor turnover.

Note that labor turnover is defined as follows:  $(\text{Head count attrition} + \text{new hires}) / (\text{beginning head count})$ ; where head count attrition is the number of employees leaving during a given year (retired, quit, fired, etc.), new hires are the number of employees hired during a given year, and beginning head count is the number of employees working in the warehouse at the beginning of the year.

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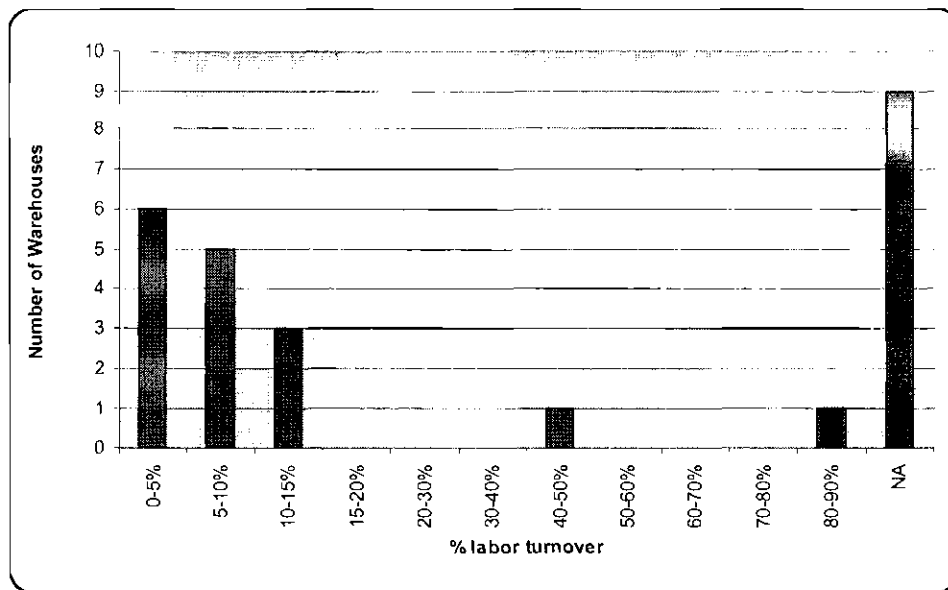


Figure 24. Labor Turnover Distribution

Labor turnover is positively correlated with the labor hours of the warehouse. This means the more labor used, the higher turnover (as a percentage) expected. This is

an indication of the relationship between a larger work force and the complexity of managing that work force. |

**Comment:** This is interesting-result 5

On average ~20% of labor is temporary. About 50% of the warehouses use a temporary labor percentage below this average. Approximately 80% of the warehouses are not unionized.

## Warehouses internal perspective

The BISG warehouses share similarities in their perspective about actual constraints for their operations and potential opportunities. This could be observed in Figures 25 and 26, which summarize the constraints and opportunities mentioned by warehouse managers. The most commonly mentioned constraints for these warehouses were layout and space limitation, followed by restrictions or inadequacies related to information technology (WMS). Problems with demand forecasting and labor were also mentioned. It is interesting that some of the constraints were also mentioned as opportunities such as improving IT, making layout changes, and getting more accurate forecasts. Labor training and tracking were pointed out several times as opportunities. Additionally, implementing new warehouse processes such as order batching and pick to light/voice were mentioned.

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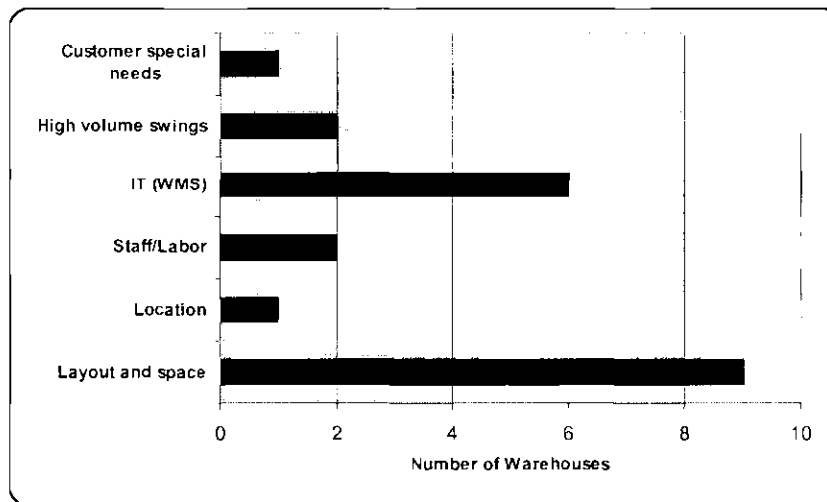


Figure 25 Self Identified Constraints Frequency Chart

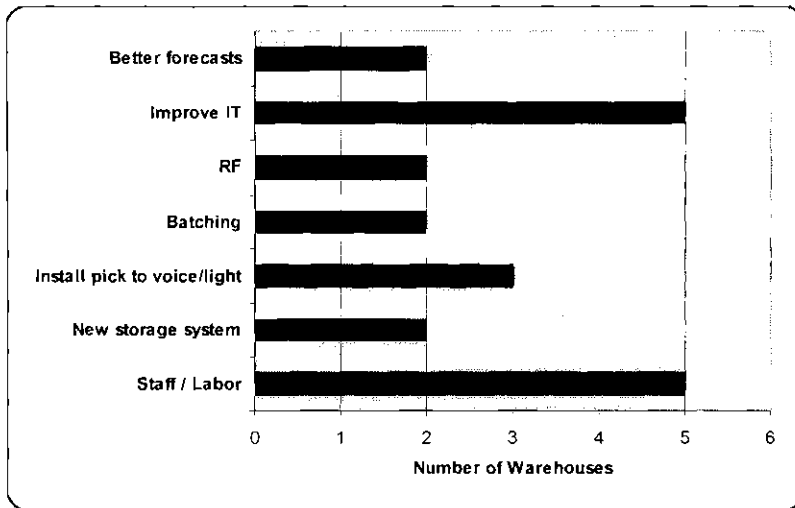


Figure 26. Self Identified Opportunities Frequency Chart

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# Performance Analysis

Performance analysis is important because it indicates which warehouses are performing well and which have room for improvement. Individual warehouse managers may benefit from performance analysis simply by learning how much room for improvement exists. However, there is another source of benefit from this which is learning what characteristics of warehouses seem to be correlated with good performance or benchmarking information.

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## Model and Metrics

The model used in this study to assess warehouse performance is a 5 output by 3 input model. Warehouses actually use other inputs and outputs, but this set of 8 measures is believed to capture the most important inputs used and outputs generated. This model was initially used by Hackman et al. (2001) on a smaller data set.

The inputs are labor, investment, and space. Labor is measured as annual labor hours including both direct and indirect labor to perform necessary operations of receiving, moving, storing, retrieving, order picking and shipping. Some indirect labor, such as management, planning, and equipment maintenance, is included. However, indirect supporting personnel, such as security, cleaning staff, office assistants, accounting, human resources, customer service, and the labor assigned to the value-adding activities are not counted. Investment is generated by taking an inventory of the equipment used in the warehouse and assigning the equipment a standard value measured in U.S. dollars, regardless of its age, then multiplying the standard values versus the quantity and summing over all equipment types. Space is the area measured in square feet, dedicated to the warehouse operations of receiving, put away, storing, retrieving, order picking, packing and shipping. Areas for supporting activities, such as offices, rest rooms, cafeteria, or break rooms are not included. Space for returns processing and value added processing also are excluded.

The outputs are broken case lines shipped, full case lines shipped, pallet lines shipped, accumulation, and storage function. When items arrive at a warehouse, they typically come in cases stacked on a pallet. Depending on the customer types and demand patterns, warehouses will receive orders requesting a certain number of each holding size: pallets, cases, or items contained in the case. An order from a customer is made up of lines. Each line is particular to a SKU, or in other words, it is particular to a certain item in a certain holding size. Thus broken case lines shipped are the number of broken case lines summed over all shipped orders for the 12 month period in which data was collected. Similar definitions apply for full case and pallet lines shipped. Accumulation is the difference between lines shipped summed over

**Comment:** is this the same as the model we all agreed to as a result of our workshops?

**Comment:** No this is not. We wanted to change storage function to buffering capacity. However, there was a lot of confusion about the number we were asking for related to buffering capacity and we ended up getting about 30% negative numbers when this number should not have been negative, so I went back to the Hackman model

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all modes and the number of orders shipped. Thus accumulation is not a ratio, but is a scalar which characterizes the effort the warehouse makes to consolidate lines picked for the same customer order. Finally, storage function is intended to characterize both the mix of storage types and the space actually needed for storage; it is computed by using the values for the number of broken case SKUs ( $B$ ), number of pallet locations ( $P$ ), and proportion of broken case lines. The exact form of the calculation of the storage function ( $S$ ) performed by iDEAS-W is:

$$S = a \cdot \sqrt{B} + (1-a) \cdot [\sqrt{25 \cdot P} + \sqrt{\text{floor storage sq ft}}]$$

where  $a = (\text{broken case lines picked}) / (\text{total lines picked})$

These measures are used to characterize the outputs of the warehouse.

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## Results

For each warehouse an efficiency estimate was calculated based on the reported inputs and outputs. Figure 27 shows the distribution of these efficiency scores. Note that Figure 27 shows the quartile distribution of the scores. The range of the efficiency scores was divided in four groups, one for each quartile, with the 4th quartile indicating top performance and the 1st quartile indicating poor performance. Then, each warehouse's efficiency score was classified in one of these four groups. The number of warehouses with a score that falls in each group is shown Figure 27.

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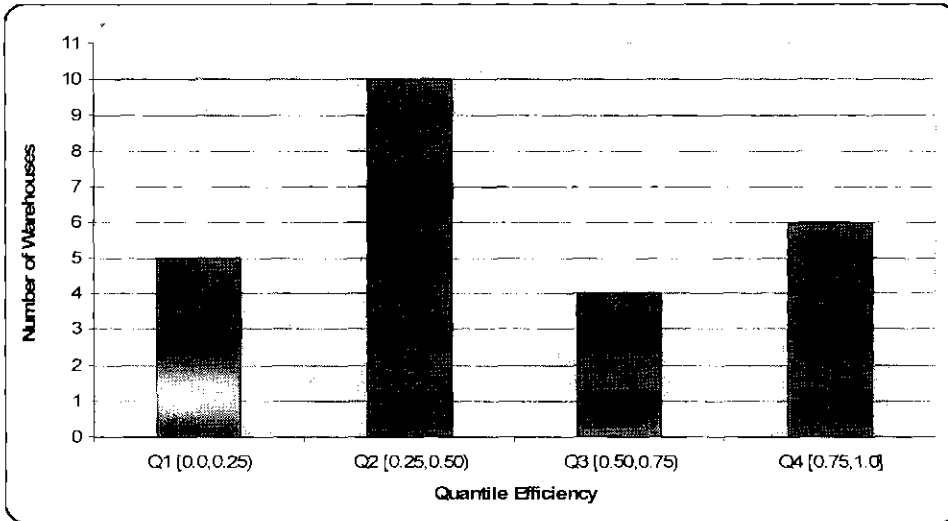


Figure 27 Quantile Efficiency Distribution

The largest portion of warehouses is in the second quartile (40%). This table shows 60% of the warehouses are operating below average performance (1st and 2nd quartile). On the other hand, 24% of the warehouses are in the fourth quartile. These warehouses are the most efficient in the group.

Figure 27 shows all warehouses. We could segment the warehouses in two main groups: publishers and distributors. Figure 28 shows the distribution of the efficiency scores, segmented by these two groups. The efficiency estimates are calculated for each warehouse compared to the entire group of warehouses. The distributions of publishers and distributors are then shown separately. The distributions of the efficiency scores for publisher and distributor's warehouses are not significantly different, both with the majority of the warehouses in the 1st and 2nd quartile, yet it can be seen in Figure 28 that publisher's warehouses tend to be more efficient, with a higher percentage of warehouses in the third and fourth quartile.

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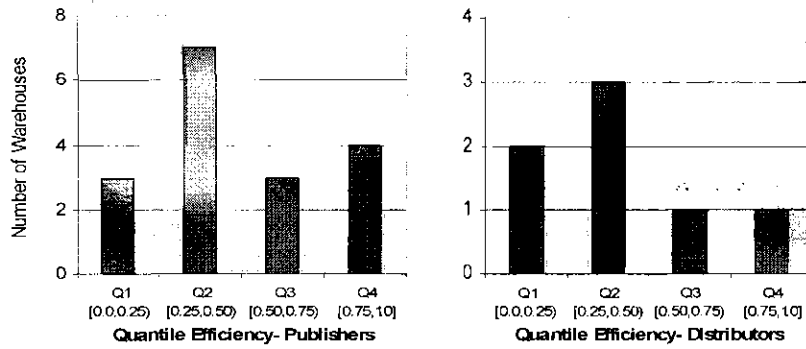
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**Comment:** Is efficiency calculated using the whole sample, and then simply reported in two groups? versus calculating the efficiencies independently for the two groups?

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Figure 28 Quantile Efficiency Distribution by Type of Warehouse

To better understand the relationship between resources used (inputs) and efficiency estimates, data were analyzed to find correlations. Warehouses were divided in two groups: the higher efficiency group (third and fourth quantile warehouses) and the lower efficiency group (first and second quantile), in order to look for significant differences between the average of the inputs used for each group. For this sample of 25 warehouses, we found the following,

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There is a positive correlation between investment and efficiency score. The warehouses with higher scores have on average a higher investment. The relation between investment and efficiency is shown in Figure 29.

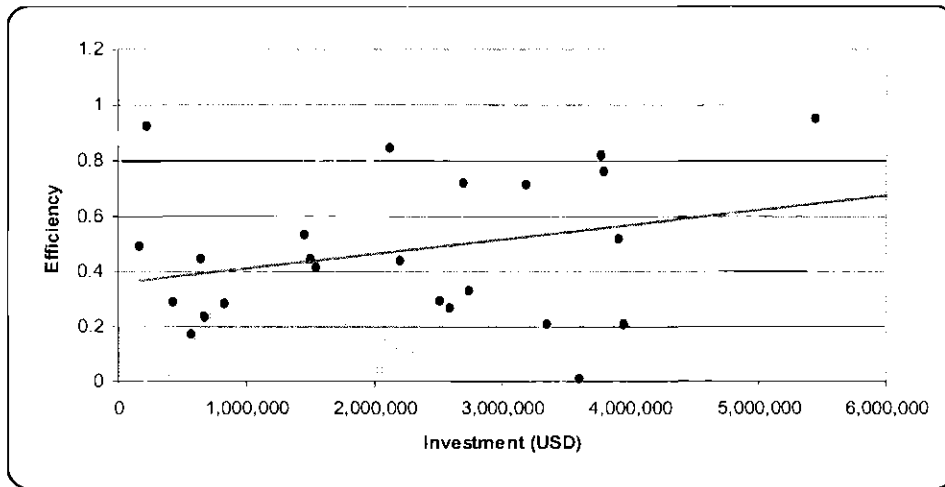


Figure 29. Efficiency vs. Investment



There is also a positive correlation between space and performance score: warehouses with higher score have on average more space. This conclusion is statistically significant. The correlation between increased input levels and efficiency estimates implies warehouses have not exhausted the benefit possible from increasing returns to scale.

**Comment:** This is interesting result 6

It is interesting to note that variables such as percentage of broken case lines and inventory turnover do not have a significant correlation with the efficiency estimates. However, seasonality does have a significant negative correlation with efficiency score. Warehouses with higher efficiency have on average a lower seasonality. This could be observed in Figure 30, where the warehouses with higher efficiency score are skewed to the left of the graph.

**Comment:** This is interesting result 7

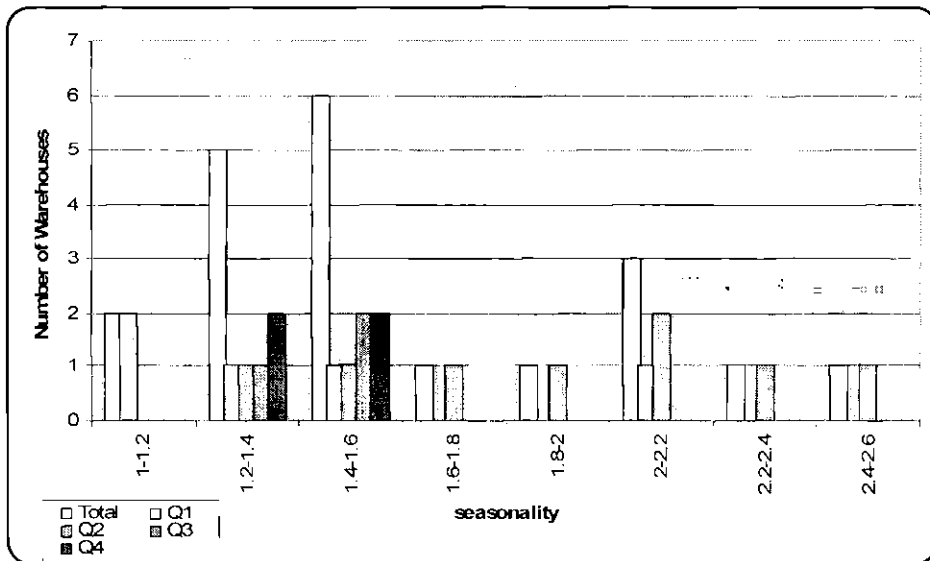


Figure 30. Quantile distribution for seasonality

Data analysis also gave evidence of some level of correlation between practices and attributes of the BISG warehouses and their efficiency estimates. For example, autosortation has a positive correlation with the efficiency score (i.e. the warehouses with autosortation systems have a higher efficiency score on average). This is compatible with the conclusion of the positive correlation between investment and efficiency. Similarly, crossdocking has a positive correlation with efficiency, while pack and hold, which is a common customer-oriented practice, has a negative correlation.

There is a negative correlation between the number of locations per title and efficiency. In general, warehouses with more locations per title tend to be less efficient than warehouses with fewer locations. Highest performing warehouses have 1 to 3 locations per title. Lowest performing warehouses have more than four locations per title.

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This suggests that having more than one location per title is not correlated with lower performance, but having too many locations is. This can be seen in Figure 31, where the quantile distribution of the average number of locations per title is shown.

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Furthermore, there is a positive correlation between the average number of titles per location and efficiency scores, when the warehouses in the first quantile and the warehouses in the fourth quantile are compared. The most efficient warehouses have on average more titles per location. This makes sense, since more titles per location increases SKU density, increasing pick density and reducing travel distance.

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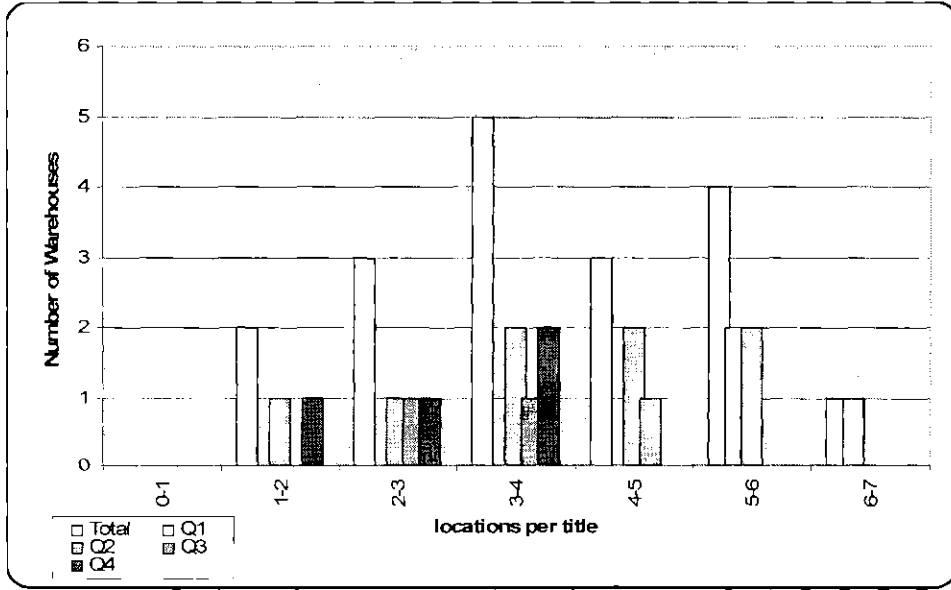


Figure 31 Quantile distribution for locations per title

Finally, inventory accuracy has a strong positive correlation with efficiency. This means that more efficient warehouses have on average higher inventory accuracy. A high level of inventory accuracy implies that the information in the IT systems is reliable; this allows the operative recommendations made from IT data to be reliable and staff members are able to use these technological tools to make better decisions while managing the warehouse resources.

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Comment: This is interesting result 8

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## Conclusions

Through the analysis of the inputs, outputs, practices and attributes of the BISG warehouses we were able to develop a big picture view of book industry warehouses. We also identified some of the variables that are correlated with high levels of efficiency, according to the data analyzed. There were some interesting observations.

- There is a great variability in the size of these warehouses. For example, the range of investment is more than 10 million USD. The other examples are operations of ~20 thousand labor hours up to ~600 thousand, and warehouses of less than 50 thousand ft<sup>2</sup> to almost 750 thousand ft<sup>2</sup>.
- The operations of these warehouses are very customer-oriented. At least half of the warehouses includes in their operations activities like: Advance notice, labeling, return process, adjustments, compliant shipping, and pack and hold.
- All the warehouses use information technology (WMS) to support their operations. However, one of the most mentioned constraints for their operations is the inadequacies related with IT.
- About 60% of the warehouses are operating below average efficiency. This represents a significant opportunity for improvement.
- For these warehouses size is positively correlated with efficiency. There is evidence that increases in efficiency due to increasing returns to scale are still possible in book industry warehouses.
- The most efficient warehouses have a lower level of seasonality.
- The number of titles per location is positively correlated with efficiency, while the number of locations per title is negatively correlated. This suggests that although a common strategy to increase picking efficiency is to have the same SKU in more than one location to allow shorter picking routes, creating separate zones and storing the same title in multiple zones may not be an effective picking strategy.

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Following these interesting observations, there are some actionable results for the BISG warehouses, in order to improve efficiency performance.

- Improve inventory accuracy
- Store products in fewer locations
- Avoid pack and hold if possible
- Extra resources are expended to meet or improve customer service. Extra resources expended in customer oriented activities must be justified. Negotiating with the customers may allow the warehouse managers to reduce resources dedicated to some of these activities.
- Crossdock products when possible
- Develop a product mix to reduce seasonality
- Build larger warehouse or merge
- Auto-sortation improves performance

**Comment:** what does this mean--how is it "actionable"?

---

## Glossary of terms

### **Accumulation**

(unit: lines) Measures the required accumulation/sortation effort. It is calculated as the difference between the total lines picked in last 12 months and the total orders shipped in last 12 months.

Note that when all orders are "single-line orders" the accumulation index is zero.

### **Advance Notice**

Practice of informing the customer about the viability to fulfill an order in quantity and time.

### **Broken Case Lines**

(unit: lines) The number of broken case lines shipped in the last 12 months.

### **Compliant Shipping**

Compliant shipping is providing customers with specific labeling or otherwise handling the item to satisfy the requests of a specific customer.

### **Full Case Lines**

(unit: lines) The number of full case lines shipped in the last 12 months.

### **Inventory (On Hand Inventory, On Hand Dollar)**

(unit: items or units) On Hand Inventory measures the number of units stored in the warehouse summed over all SKUs.

(unit: \$) On Hand Dollar measures the total inventory in terms of the value of the items stored.

### **Inventory Turnover**

A ratio that shows how many times the inventory of a firm is sold and replaced over a specific period.

### **Investment**

(unit: \$) Represents the value of the equipment invested. Rather than attempting to capture actual cost, or book value, for this study an equipment inventory was captured, and then a standard cost was applied to determine an equipment investment that is normalized across all warehouses.

### **Items**

Is the number of physical units requested depending on variant modes, e.g. pallet, case, or each (piece).

**Labor (Labor Hour)**

(unit: hr) Labor is measured as annual labor hours including both direct and indirect labor to perform necessary operations of receiving, moving, storing, retrieving, order picking and shipping. Some indirect labor, such as management, planning and equipment maintenance are included. However, indirect supporting personnel, such as security, cleaning staff, office assistants, accounting, human resources, customer service, and the labor assigned to the value-adding activities, should not be counted. To determine hours from head counts we assumed that each full time equivalent person worked 2,000 hours per year.

**Labor Turnover**

Turnover is defined as:  $(\text{Head count attrition} + \text{new hires}) / (\text{beginning head count})$ . Head count attrition is the number of employees left during a given (last) year (retired, quit, fired, etc.). New hires is the number of employees hired during a given (last) year. Beginning head count is the number employees working in the warehouse at the beginning of a given (last) year.

**Line**

Line is also called "product" or "SKU". Number of lines is the number of different product types in an order.

**Maintenance Expense**

Percentage of maintenance expense comparing to total operating budget measures the maintenance intensity. Maintenance expense should NOT include support services or value adding services.

**Orders**

Customer orders specify the details of customer demand which a warehouse needs to fulfill. A customer order generally includes product types (SKU) and the quantity for each product type.

**Pallet Lines**

(unit: lines) Number of pallet lines shipped (shipped in pallets) in the last 12 months.

**Seasonality Index**

The seasonality index is defined as  $(\text{volume in the peak month} / \text{average volume per month})$ , where volume is based on items (pieces, or units).

**Planning Horizon**

The planning horizon refers to how far into the future to use information (demand, order composition forecast) in making the current decisions.

**Response Time**

Response time is defined as the time between an order arrival and the order completing within the warehouse.

**Rush Order**

The order requiring to be handle in rush.

**Rush Line**

The line requiring to be handle in rush.

**SKU Span**

(units: number of SKUs) The number of active SKUs

**SKU Pareto**

Percentage of the total SKUs that represents the 80% of the activity of the warehouse, measured in terms of total lines or total volume shipped.

**SKU Turnover (SKU churn)**

This metric captures that volatility. The question of "What fraction of skus changes from year to year? " is used for this metric, and it is defined as  $(\text{skus dropped last year} + \text{skus added last year}) / (\text{beginning total skus last year})$ .

**Slots (occupied)**

A slot is a designated location where you store stuff. It could be a pallet location on the floor, or a pallet storage "lane". It could be a rack location, or a shelf location. The key is that it's identified, so, for example, you could dispatch an order picker to the location to retrieve items.

Average storage space utilization based on avg number of slots occupied (%) asks, what percentage of your slots actually have something in them?

**Space**

(unit: sq. feet) Space is the area (measured in square feet) dedicated to the warehouse operations of receiving, put away, storing, retrieving, order picking, packing and shipping. Area for supporting activities, such as office, rest room, cafeteria or break room, is not included. For multistory buildings, total square footage should be reported, rather than building footprint. However, multistory buildings will be an attribute captured to reflect the construction cost and operation environment.

**Supervision and Management Expense**

Percentage of supervision and management expense comparing to total operating budget measures the maintenance intensity. Maintenance expense should NOT include support services or value adding services.

**Task Interleaving**

Task interleaving is the alternation of various tasks, as opposed to doing all the picking at once, followed by the packing, etc.

**Total Replenishment Number**

Counts the replenishment (inbound) activities and is the annual total number of replenishment for all skus. For example, if you have sku A and B only, and A restocked twice and B restocked 12 times last year, the total number of replenishment is 14.

**Velocity-Based Slotting**

Assigning items to storage locations based on the frequency of their retrieval.