ASSESSMENT OF PR MANUFACTURING READINESS WITH RESPECT TO COMMUNICATION AND INFORMATION TECHNOLOGY AND ITS IMPACT ON PRODUCTIVITY

By

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ABSTRACT

This work presents a statistically robust assessment to evaluate the use of real-time data collection and reporting systems in the shop-floor of Puerto Rico manufacturers. The survey was published in the internet with a high response rate that covered five sectors: electronics, electromechanics, medical devices, pharmaceutical and plastics. It can be concluded that less than 50 percent of the companies sampled have some real-time data collection and reporting capabilities. Also the information generated from these systems might not be used effectively due to low line employee involvement. The assessment requested the productivity metrics in use and the results achieved during the years 2000 and 2002. The variety of productivity metrics and the few numeric responses signal that there is little productivity information available. Finally, it was not possible to establish a relation between real-time data collection and reporting and productivity on the shop-floor.

RESUMEN

En este trabajo se presenta una encuesta estadísticamente robusta para evaluar el uso de sistemas de recolección y reporte de datos en tiempo real en el área de producción de las fábricas puertorriqueñas. Esta encuesta fue distribuida usando el Internet con un alto porciento de respuestas y cubrió cinco sectores industriales: farmacéutico, aparatos médicos, electrónica, electromecánica y plásticos. Se concluyó que menos del 50 porciento de las empresas encuestadas tiene establecidos sistemas de recolección y reporte de datos en tiempo real. Además, la información generada por estos sistemas no necesariamente se usa efectivamente debido al poco uso por los operadores. La encuesta recoge información de las métricas de productividad usadas y los resultados obtenidos en los años 2000 y 2002. La variedad de métricas y las pocas respuestas numéricas indican que hay poca información de productividad disponible. Finalmente, no fue posible establecer una relación entre la recolección y reporte de datos en tiempo real y la productividad en la línea de producción.

DEDICATION

God:

- *For always allowing me to make the right decisions and for allowing me to see the light at the end of the tunnel even when I only see shadows. For forgiving my mistakes and always making me a better person.*

To my family: (Mami, Papi, Alex, Brenda & Annie)

- *For always being there. Love is not just saying it everyday, but showing it when you needed the most. Thank you for understanding that sometimes things are important even when you don't understand what I mean. Thank you for taking care of me and supporting me in the happy and in the sad times. Now it is my time to care for you…*

To my other family: (Damaris, Ivelisse & Victor, Yesenia & Omar, Kriselie & Manuel)

- *We have been through so much… I definitely needed to recognize your importance in my life. Guess we do not say it much but I love you and I will always be there. We grew up together to become the adults we are today. Let's enjoy the good times that are coming and go get a vacation!!*

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CHAPTER 1 - INTRODUCTION

1.1 INTRODUCTION

Communication and Information Technology (***C&IT***) can be defined as a set of technology advancements that facilitate the collection and reporting of information of interest being generated by an active system. The C&IT environment consists of computer hardware, computer software and telecommunications equipment. Hardware components can include: personal computers, storage devices and peripherals such as bar-code readers; software can include applications for data acquisition, storage & retrieval; and telecommunications equipment can include data transfer components like routers and cables.

Since the technology is just part of any successful system; it is important to recognize the importance of the procedures that will rule the system as well as the discipline enforced in its successful execution. It is also important to understand that any successful C&IT system needs to have some intelligence that will give instructions to the users (e.g. equipment operators in manufacturing) in order to avoid improvisation and sub-optimal decisions.

This thesis will focus on the evaluation of the Communications and Information Technology (C&IT) capabilities in Puerto Rico's manufacturing industries. C&IT solutions have been available for decades; but in recent years functionality and cost for hardware and software have improved substantially to allow manufacturers to benefit from C&IT implementation. As automatic data collection processes have emerged; businesses can maintain and analyze large quantities of data. This data can be available right away to make decisions that may affect quality, throughput and productivity on the manufacturing shop floor.

As the International Standardization Organization (***ISO***) of the European Union requires the definition and monitoring of the processes and as clients have become better informed customers; it is more critical than ever to monitor, maintain and control the processes necessary to manufacture a quality and safe product. It is especially important for the regulated sectors (pharmaceutical, chemical and medical devices) to consider C&IT implementation as part of the tools to maintain an effective quality system.

This work will identify relevant productivity metrics used by manufacturing industries in Puerto Rico in five main sectors: pharmaceutical, medical devices, electronics, electromechanics and plastics. Relevant information extracted from the questionnaire will be summarized in each chapter. Also, statistical analysis will be performed to relate C&IT usage with higher productivity performance.

Manufacturing companies that currently make no use of C&IT tools might decide to invest in C&IT solutions if the correlation between C&IT and productivity is demonstrated. This work will try to prove the hypothesis that productivity is positively correlated with C&IT implementation. In the following chapters the steps taken and the results achieved will be presented.

1.2 OBJECTIVES

1. Design a web-based questionnaire to assess Puerto Rico’s industry standing in C&IT.

2. Perform statistical analysis on the results for this questionnaire and make statistical inferences:
    a. Compare industries by:
        i. Sector
        ii. C&IT data collection/reporting
        iii. Productivity Measures

3. Identify industries were C&IT implementation has not been started, explore their reasons and give recommendations.

4. Identify the personnel that are involved with C&IT deployment and use in Puerto Rico's manufacturing industries.

5. Relate C&IT's correlation with Productivity in Puerto Rico's manufacturing industries.

6. Identify potential C&IT suppliers and facilitate strong teamwork between customers (manufacturing companies) and suppliers (C&IT solution providers).

1.3 ORGANIZATION

This chapter presents an introduction to the problem and the key objectives to be completed in this work.

Chapter 2 presents the Literature review, which has been divided in four focus areas: C&IT justification, C&IT assessments around the world, productivity measures in use and statistical design and analysis of questionnaires.

Chapter 3 initiates with an eleven step methodology to be followed throughout the research. This effort requires interaction with the Puerto Rico Industrial Development Company (***PRIDCO***), which maintains updated information on manufacturers doing business in Puerto Rico. The flowchart also includes a reliability exercise conducted with respondents of the questionnaire.

Chapter 4 gets inside the C&IT questionnaire wanting to discuss the most relevant questions of this study. Charts describing companies with real-time data collection and real-time reporting are presented as well as information about areas where data is collected. Also information about companies that do not collect this data and their criteria for not engaging in these processes is presented.

Chapter 5 continues to present information about the C&IT assessment but focused in productivity. It presents charts for the use of different productivity metrics by respondents of the survey. For companies that provided the value of their productivity metric an analysis to relate the value of productivity and their implementation of C&IT is also presented. Also, a metric that will allow companies from different sectors to compare their productivity is suggested. A case study with an example of the metric calculation is also included. Chapter 6 presents the conclusions of the research and recommendations for future research in the area.

CHAPTER 2 - LITERATURE REVIEW

The literature review has been divided in the following areas:

1. Communication and Information Technology (C&IT) justification.
2. C&IT assessments around the world.
3. Productivity measurements around the world.
4. Statistical Design and Analysis of Questionnaires.

2.1 COMMUNICATION AND INFORMATION TECHNOLOGY

Communication and Information Technology tools are widely present in all aspects of our daily life. From Harchaoui: "the proliferation of C&IT has made the world seen much smaller, as computer innovations let individuals in opposite sites of the world interact in unimagined ways. Since computers became available in the 1950's their uses in the manufacturing sectors have been widely discussed, and until today, there is a constant search to find new applications for these devices". [Harchaoui-2002]

Most early studies of manufacturing and service sector films find little or even negative impact of C&IT [Mukhopadhyay-1997]. The first wave of empirical analysis of C&IT done in the late 1980's and early 1990's found little evidence that the use of computers increased output (this was called the "productivity paradox"). More recent studies have found productivity effects of C&IT above their investment cost [Zwick-2003]. The absence of productivity effects in the earlier studies is attributed to small sample sizes and noisy data [Zwick-2003]. Also responsible for the 1980's failures in C&IT was Computer Integrated Manufacturing (***CIM***) due to its high investment costs and the poor results achieved.

As C&IT has become a research subject, some claim that its main deliverable for economic growth is productivity [Pilat-2003]. Pilat explains that: "countries with a strong investment in C&IT not only have economic growth, but also show a slower economic decline and better economic recovery capacity”.

Many countries have experienced economic growth with the use of C&IT including Canada, the United Kingdom and the United States [Harchaoui-2002]. Table 1 show that C&IT has become an important contributor in the economic growth in the US, representing 20 percent of the total growth rate from 1995 to 1999 [Harchaoui-2002].

Source of economic growth	Value	Contribution to total growth rate (%)
Labor input	1.8	36.73%
C&IT	1	20.41%
Other machinery and equipment	0.4	8.16%
Structures	0.4	8.16%
Multifactor productivity	1.3	26.53%
Total (annual average growth rate)	**4.9**	

Table 1 Economic growth in the USA and Canada 1995-1999

Government policies for business management and technology are an important factor related to the variation of C&IT between nations. A competitive business environment will motivate firms to invest on C&IT as a way to strengthen performance and ensure survival [Pilat-2003]. Another important factor is the involvement from government agencies that promote industrial development to show interest in exploring alternatives for real time data collection that should improve manufacturing results for small to middle-size industries.

C&IT capital investment is quite important for growth. It has accounted for a 0.3 to 0.8 percentage point of growth in labor productivity over the 1995-2001 period. [Pilat-2003] This investment is necessary for firms to integrate C&IT into their processes to increase the overall combined efficiency of labor and capital together – called by economists' multi-factor productivity (***MFP***) [Pilat-2003]. This measure shows productivity improvements as a result of C&IT since it can capture changes in capital and not just in labor efficiencies as basic labor productivity metric does. Also, the use of C&IT may help firms expand their product range, customize their service and respond better to demand, in short, to innovate and gain market share. It also allows managers to control inventories [Pilat-2003].

As Pilat states: "there is a risk in over investing on C&IT, as well as misdirecting the technology". Unplanned investment in a bid to compensate for a lack of skills or competitiveness is not an answer either. It takes time to adapt to C&IT investments, to find the adequate devices, the best personnel to manage the change and to change the organizational culture in order to be successful with the investment.

Another issue that has not been addressed yet is the confidence of the public and of the people that use the C&IT tools in the manufacturing industry. Some advances have been achieved by governments that have embraced e-tools; but still some issues need to be addressed to reduce uncertainty and improve security. Also another important aspect is that these tools need to be adequate to the manufacturing sector where they will be used; for example, in the pharmaceutical sector, Food and Drug Administration (***FDA***) regulations require devices included in the processes to be validated, in other sectors regulations of security or environmental health and safety may limit the use of some equipment.

2.2 C&IT ASSESSMENTS AROUND THE WORLD

Countries such as Germany and Canada have developed and used C&IT assessment tools to analyze their industries and suggest improvements. Hitt and Brynjolfsson comment that the critical questions for an economic evaluation of C&IT should include [Hitt-1996]:

- Has investment in C&IT increased productivity?
- Has investment in C&IT increased business profitability?
- Has investment in C&IT created value for customers?

Some of the key variables in Hitt and Brynjolfsson were: value added, IT stock, non-computer capital, labor expense, return of assets, return on equity, shareholder retention, IT stock employees, capital investment, sales growth, market share, debt and R&D stock [Hitt-1996].

In Germany [Zwick-2003] a parent sample of German establishments was selected. The random sample included 1400 companies in the year 2000 [Zwick-2003]. The companies on this German survey were asked about turnover, number of employees, any personnel issues and relevant performance measures [Fraenkel-2003]. No question was made regarding investments made on the year of the survey.

The productivity effects of C&IT were calculated with the Cobb-Douglas production functions using the economic value added (turnover minus input costs) as response variable and capital, number of employees, and dummy variables for C&IT investment as independent or explanatory variables.

In a Canadian research [Beckstead-1998] the following aspects were covered:

- General plant characteristics
  - nationality of ownership
  - average plant size
  - market structure
  - the extent of competition
  - Average number of employees working in the plant
  - Domestic and Foreign Competitors (establishment weighted)
  - Business Strategies
- Technology
  - CAD/CAE
  - CAD/CAM
  - programmable logic controllers
  - local area networks (LANs)
  - company-wide computer networks
  - Investment of Technology
  - Technological Competitiveness

- Communication Networks
- Business Practices
- Skills
- Adoption
  - Results
  - Obstacles

With this information the Canadian government performs an analysis of its industries in C&IT and AMT (advanced manufacturing technology).

2.3 PRODUCTIVITY

The ability that a company has to manage its assets in a way that they are productive will usually define the success or failure of any business. The word productivity is commonly used but does not necessarily mean the same to all enterprises. These sections will try to describe some of the most common definitions for productivity.

2.3.1 DEFINITION

Productivity is a measure of economic efficiency which shows how effectively economic inputs are converted into output. Productivity is measured by comparing the amount of goods and services produced with the inputs used in production.

2.3.2 PRODUCTIVITY MEASURES

The most common measures of productivity are labor productivity, multifactor productivity and cost productivity. These measures are widely used worldwide. The Bureau of Labor Statistics (***BLS***) is the agency that is required by law to define productivity measures in the USA.

It is important to define some critical terms in the definition of productivity measures. The first term is output. Steindel defines output in two contexts [Steindel-2001]:

- Value Added Output – is a measure of the profit since it subtracts the cost of goods and services from the value of goods sold. This is the same as subtracting the cost of goods and services from the gross output.
- Gross Output – this is the total value of the sales in an economic unit.

The second key term is input, which considers the various ingredients that are needed to complete the needed output. Various productivity metrics are discussed below, each one focusing on one or various inputs.

2.3.2.1 LABOR PRODUCTIVITY

Labor productivity is the ratio of the output of goods and services to the labor hours devoted to the production of that output. Output per hour of all persons, labor productivity, is the most commonly used productivity measure. Labor is an easily-identified input to virtually every production process. There are some deviations from the same metric; including: output per all workers, output per salaried workers and output per some time period. The output can be described as dollars shipped, sales or other important quantitative measure considered as output.

2.3.1.2 MULTIFACTOR PRODUCTIVITY

Multifactor productivity relates output to a combination of inputs used in the production of that output, such as labor and capital or labor, capital, energy and materials. Capital includes equipment, structures, inventories, and land.

As stated by Steindel, this measure captures the overall inputs responsible for creating the outputs, and can reflect the impact of factors such as: gains in efficiency, allocation of resources and others. In his study, he also cites that this factor allows seeing the improvements in productivity associated with technology.

A variation from the multifactor productivity metric given before is the KLEMS multifactor productivity presented by the Bureau of Labor Statistics. The BLS defends this metric as a measure of efficiency over labor productivity. The BLS provides the equations for the productivity indexes, measuring the relation between the output and the quantity of input required to produce the output. Some of the inputs described for this equation are the capital and intermediate purchases and the labor input.

The concept is based on an economic concept named the Tornqvist index and is expressed as:

$$\ln\left(\frac{A_t}{A_{t-1}}\right) = \ln\left(\frac{Q_t}{Q_{t-1}}\right) - \left[w_k \cdot \left(\ln\left(\frac{K_t}{K_{t-1}}\right)\right) + w_l\left(\ln\left(\frac{L_t}{L_{t-1}}\right)\right) + w_{ip}\left(\ln\left(\frac{IP_t}{IP_{t-1}}\right)\right)\right]$$

The use given to this equation and the final description of the productivity metric used will be described in the next sections (look for the symbols definition in Appendix 8).

2.3.1.3 COST PRODUCTIVITY

Measurement of cost productivity per unit calculates the cost of producing one unit and is determined by dividing the total production cost by the number of units manufactured in a specific timeframe. Calculation takes into account the total cost accrued by the production line in a time period and divides by the total number of units produced during a same time period [Maskell-1991]. This measure will give a clear indication of the net effect of the cost-saving improvements that can be introduced in a manufacturing industry [Maskell-1991].

2.3.3 PRODUCTIVITY IN PUERTO RICO

This is PRIDCO’s pitch line for advertising the island: “Puerto Rico is the lowest labor cost region in a restructured, competitive U.S. economy. The average hourly compensation production costs in Puerto Rico are $ 13.47 (2000 data) compared to $17.94 (2000 data) in the U.S. mainland. Hourly earnings in Puerto Rico’s manufacturing sectors - 2-digit SICs - (s***ector indicator code***) are on average between 65 % and 80 % of the overall in the US. Labor costs in Puerto Rico are lower than most competing locations for high technology industries." [PRIDCO-2003]

2.4 SURVEY DESIGN ISSUES

The questionnaire used in this thesis will measure the present level of implementation of C&IT in Puerto Rico's manufacturing industry. At this moment the questionnaire represents a cross sectional survey since it collects data at one point in time from a predetermined population or populations [Fraenkel-2003]. In a one to three years timeframe, UPRM researchers will distribute the questionnaire once more to measure change. Issues such as sample size, reliability, validity and analysis of data will be described in the following sections.

2.4.1 STRATIFIED RANDOM SAMPLING

In this method the population of N units is subdivided into sub-populations of N_1, N_2 to N_L units, respectively. This subpopulations are not overlapping and, and their sum is the population N. These subpopulations are called the strata. The total number of items in each stratum should be known and a sample will be drawn from each stratum; this sample sizes will be noted as n_1, n_2 to n_L , respectively. If a random sample is taken from each stratum this method be defined as stratified random sampling. [Cochran-1977]

2.4.1.1 DEFINITION

The theory of stratified sampling deals with the properties of the estimates in the stratified sample and the selection of a sample size n_h in search of maximum precision. Stratification is a common technique and the principal reasons for it are [Cochran-1977]:

- If data of known precision are wanted for certain subdivisions of the population, it is advisable to treat each stratum as a "population".
- Sampling problems will be different for different parts of the population

Stratification could produce a gain in precision in the estimates of characteristics of the whole population. It will allow the division inside populations that will allow internal homogeneity.

2.4.1.2 SAMPLE SIZE ESTIMATION

The general formulas for sample size estimation will be derived from the equations used to estimate the mean of the population $\overline{Y}$. The following steps will explain the required derivations to find the sample size n:

Let s_h be the estimate of S_h and let $n_h = w_h \cdot n$ where w_h has been chosen. With these terms the calculated variance (V) for the average is:

$$V = \frac{1}{n} \cdot \sum \frac{W_h \cdot S_h}{w_h} - \frac{1}{N} \sum W_h \cdot S_h^{\,2} \tag{2.1}$$

where $W_h = \dfrac{N_h}{N}$

A general formula for n:

$$n = \frac{\sum \dfrac{W_h^{\,2} \cdot S_h^{\,2}}{w_h}}{V + \dfrac{1}{N} \cdot \sum W_h \cdot s_h^2} \tag{2.2}$$

If the finite population correction is ignored, a first approximation is given by:

$$n_o = \frac{1}{V} \cdot \sum \frac{W_h^{\,2} \cdot S_h^{\,2}}{w_h} \tag{2.3}$$

If $\dfrac{n_0}{N}$ is not negligible, i.e., the finite population consideration must be taken into consideration, n will be calculated with:

$$n = \frac{n_o}{1 + \dfrac{1}{N \cdot V} \cdot \sum W_h \cdot S_h^2} \tag{2.4}$$

The specific technique to be used in our work is the stratified sampling for proportions. It will be possible to construct strata such that a proportion in a class C varies as much as possible in each sample. [Cochran-1977]

Let:

$P_h = \dfrac{A_h}{N_h}$ and $p_h = \dfrac{a_h}{n_h}$ (equations 2.5) be the proportions of units in C in the h_{th} stratum and in the stratum, respectively.

The random sampling estimate for the whole population proportion is:

$$p_{st} = \sum \frac{N_h \cdot p_h}{N} \tag{2.6}$$

With the general equations presented from 2.1 to 2.4 and letting V be the desired variance in the estimate of the proportion P for the whole population the sample size will be given by:

The proportional allocation is obtained from the following two equations considering the finite population:

$$n_o = \frac{\sum W_h \cdot p_h \cdot q_h}{V}$$

$$n = \frac{n_o}{1 + \frac{n_o}{N}} \tag{2.7}$$

These are the equations for the presumed optimum technique also considering finite population:

$$n_o = \frac{\left(\sum W_n \cdot \sqrt{p_h \cdot q_h}\right)^2}{V}$$

$$n = \frac{n_o}{1 + \frac{N}{V} \cdot \sum W_h \cdot p_h \cdot q_h} \tag{2.8}$$

The value of V can be found as the ratio $(d/t)^2$ where d is a margin of error and t is the x value of the normal curve that cuts off an area of α at the tails.

The best selection of the sample size n_h in order to minimize $V(p_{st})$ which provides a minimum variance for the fixed total sample size is given by:

$$n_h = n \cdot \frac{N_h \cdot \sqrt{P_h \cdot Q_h}}{\sum N_h \cdot \sqrt{P_h \cdot Q_h}} \quad (2.9)$$

2.4.2 RELIABILITY AND VALIDITY

Before a questionnaire is distributed the analyst must be certain that the survey will be fully understandable for the level of knowledge of the respondents. Two important issues come into play to measure the degree of understanding and consistency in a survey [Fowler-1993]:

- Reliability – provide consistent measures in comparable situations
- Validity – Answers are appropriate for what they intent to measure

If two or more respondents answer to a question in the same situation it should be answered in the same way. A question with that property can be considered reliable. Inconsistencies in measures introduce random error and reduce precision. Some issues can affect the reliability of questions are [Fowler-1993]:

- Ambiguity of wording
- Standardization of presentation
- Vagueness in response form

The assumption that should dominate is that the differences in the answers come from the difference in scenarios for which the survey is applied and not of the perception the questions provide to the respondents. This can be addressed with the wording in the questions. To assure consistency in data collection, questions should have the following properties [Fowler-1993]:

- The question as written prepares the respondent to answer it
- It means the same to every respondent

- The possible answers that can be considered as appropriate should be communicated consistently to all respondents.

Accuracy in a response will basically mean that the question is answered by the respondent the same way the researcher would if he/she had the same information. Four reasons can be mentioned on why respondent answer fails in accuracy:

- The question is not understood
- The respondents do not know the answer
- The answer can not be recalled, even when it is known.
- The respondent does not want to report the answer in the interview content.

A qualitative way to calculate the reliability in a survey is known as the Cronbach's Alpha. This is used to calculate the internal consistency of a questionnaire. Equation 2.10 is used for this analysis

$$\alpha_k = \frac{k^2 s_p^2}{k^2 s_p^2 + k s_{res}^2} \tag{2.10}$$

The questionnaire is considered reliable if the value of α_k is over 0.7.

The validity in subjective questions is different from that in objective questions. Some recommendations are presented in order to improve subjective questions validity:

- Make the questions as reliable as possible (focus on the three issues presented earlier)
- Consider including the maximum possible number of categories that the respondent can respond to without being overwhelmed.
- Consider asking the same question in multiple ways and then combine the answers into a scale.

An online questionnaire can correct some of the issues of validity and reliability. Internet page designs will allow the surveys to be dynamically generated – the survey will be generated depending on the answers of previous questions. If a question could be ambiguous to some respondents a help page can be easily created for quick reference. Also, the idea to use the Web allows the answers to be recorded in a centralized place – the web server – for easy retrieval and analysis.

2.4.3 DATA ANALYSIS

Data analysis allows the quantification of the responses of the survey in an organized manner. Relevant conclusions reveal themselves during this process and may later be recognized as breakthroughs that benefit our society.

2.4.3.1 RESPONSE RATE

An important measure in any survey is the response rate, which is the proportion of companies that answered the questionnaire after being asked by the researcher. The non-respondents include all those that were selected but did not respond for reasons such as lack of time or lack of interest in participating in the study.

2.4.3.2 DISPERSION AND LOCATION MEASURES

The mean and the standard deviation are calculated for the entire stratum in the sample and for the whole sample using Cochran's equations for the stratified sample method:

the sample mean will be given by: $$\bar{y}_h = \frac{\sum_{i=1}^{n_h} y_{hi}}{n_h} \tag{2.11}$$

Where $\bar{y}_h$ is the average value in the stratum, n_h is the number of items per stratum and y_{hi} are each of the i items in the h stratum.

For the population mean per unit, the estimate used for stratified sampling is $\bar{y}_{st}$, whose calculation is given by:

$$\bar{y}_{st} = \frac{\sum_{h=1}^{L} n_h \cdot \bar{y}_h}{N} = \sum_{h=1}^{L} W_h \cdot \bar{y}_h \text{ , where } N = N_1 + N_2 + \ldots + N_L \tag{2.12}$$

It has to be noted that there is a difference between the population mean per unit and the same mean. In $\bar{y}_{st}$ the estimates from the individual strata receive their correct weights $W_h = \frac{N_h}{N}$. The samples mean for y can be defined as:

$$\bar{y} = \frac{\sum_{h=1}^{L} n_h \cdot \bar{y}_h}{n} \tag{2.13}$$

These two quantities will be the same if the sampling fraction is the same for all strata.

If a simple random sampling is taken with each stratum, an unbiased estimate for the stratum variance σ_h^2 is:

$$s_h^2 = \frac{1}{n_h - 1} \cdot \sum_{i=1}^{n_h} \left(y_{hi} - \bar{y}_h \right)^2 \tag{2.14}$$

An unbiased estimate of the variance of $\bar{y}_{st}$ is:

$$s^2(\bar{y}_{st}) = \sum_{h=1}^{L} \frac{W_h{}^2 \cdot s_h^2}{n_h} \cdot \sum_{h=1}^{L} \frac{W_h \cdot s_h^2}{N} \tag{2.15}$$

The formula for the confidence interval is given by:

Population mean: $\bar{y}_{st} \pm t_{\alpha/2,n-1} \cdot s(\bar{y}_{st})$ (2.16)

The formula assumes that $\bar{y}_{st}$ is normally distributed and that s($\bar{y}_{st}$) is determined, so that the multiplier t can be read from tables of the normal distribution. If not, t will be read from the t distribution table with degrees of freedom n-1.

2.5 CONCLUSIONS

The present chapter tried to describe the present literature to justify and construct a survey to assess communication and information technology capabilities in Puerto Rico's industries. It also showed some of the tools that will be used once the survey concludes to perform appropriate statistical analysis. Most of these tools will be amply described in the following chapters.

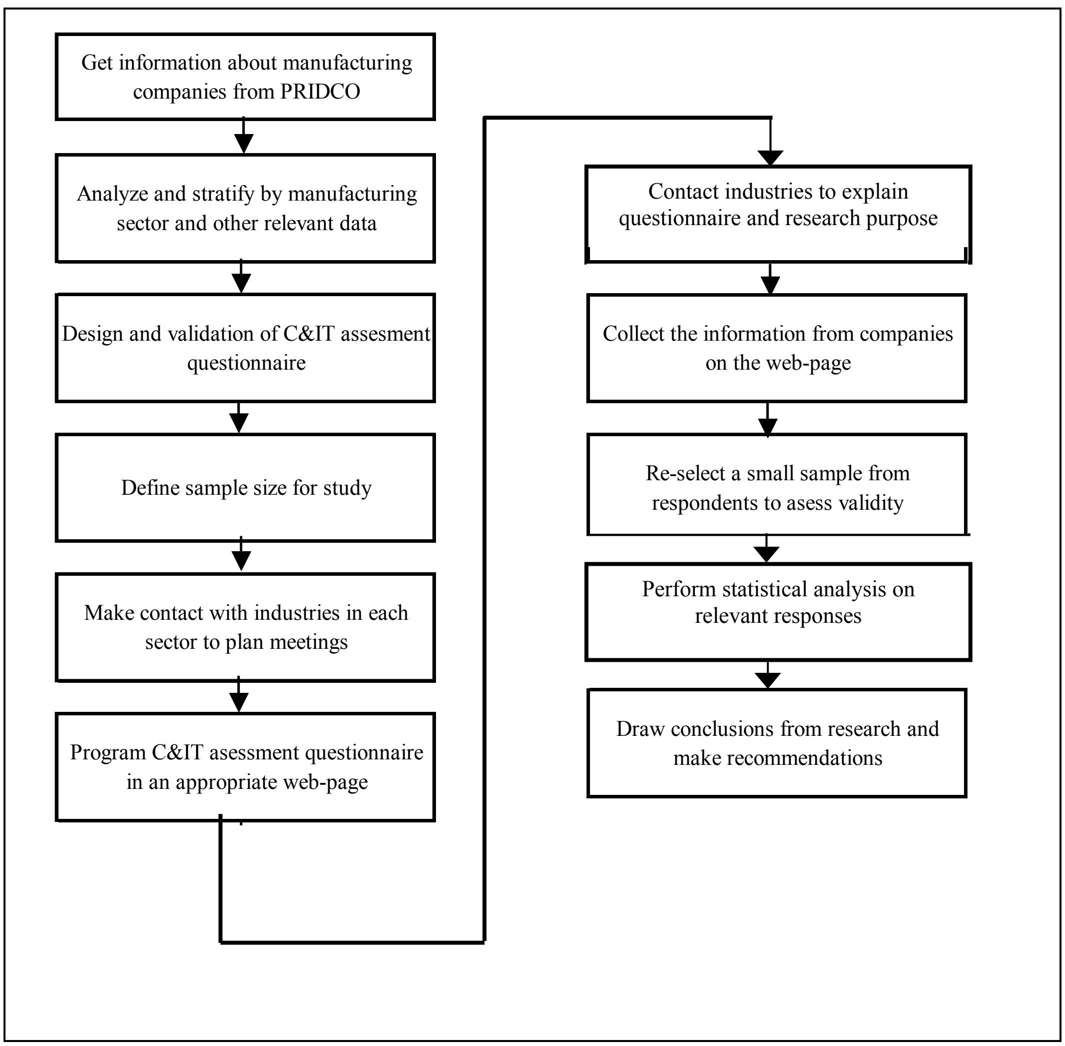
Another important aspect of this research is the definition in the productivity metrics used by the manufacturing sectors. An important aspect to be discussed in the following chapters is the importance of using the same productivity metric thought the plants to simplify comparisons between manufacturing sectors.

CHAPTER 3 - METHODOLOGY

3.1 INTRODUCTION

The methodology used in the present work includes four major tasks: (1) definition of the manufacturing companies' population, (2) design of the questionnaire considering validity and reliability issues (3) design of the web base application and data-collection interface and (4) identification and analysis of the responses.

Figure 1 Thesis methodology



3.2 PROBLEM DEFINITION

This thesis focuses on understanding the use of Communication and Information Technology in the shop-floor for Puerto Rico's manufacturing sector. An assessment will inform the actual status of our industries and the opportunities for improvement. The various productivity metrics used by the companies will be analyzed and an effort will be made to correlate the industries productivity metrics to the C&IT investments.

3.3 INFORMATION COLLECTION ABOUT MANUFACTURING COMPANIES FROM PRIDCO

The critical task on this step is obtaining the information from PRIDCO about manufacturing industries in Puerto Rico. PRIDCO's plant database is a valuable tool in the data collection phase. Relevant data was extracted including company name, location, description, number of employees and contact information. The database was quite extensive with information on registered companies within different industrial sectors. Over 200 sectors and subsections are available. The necessary information from each company was retrieved in preparation for the next step in the methodology.

3.4 ANALYSIS AND STRATIFICATION BY MANUFACTURING SECTOR

The relevant strata for our study come from five important sectors in Puerto Rico's manufacturing industries: plastics, medical devices, electronics, electromechanics and chemical & pharmaceutical. These five sectors have over 200 companies listed in PRIDCO's database. It was decided to consider only those companies with 100 or more employees, assuming that this have bigger challenges for workforce retention and growth and should have better chance for C&IT funds allocation. Selected companies total 185, broken down by sectors on Table 2.

Population Size	Sector	Percent of Population
72	Chemical & Pharma	38.90%
39	Electromechanical	21.10%
35	Medical Devices	18.90%
23	Plastics	12.40%
16	Electronics	8.60%
185	Total	

Table 2 Total companies available for the study

The plant population encompasses 50 cities and towns in Puerto Rico. This is presented in Figure 2. (Pareto shows 80% of the data)

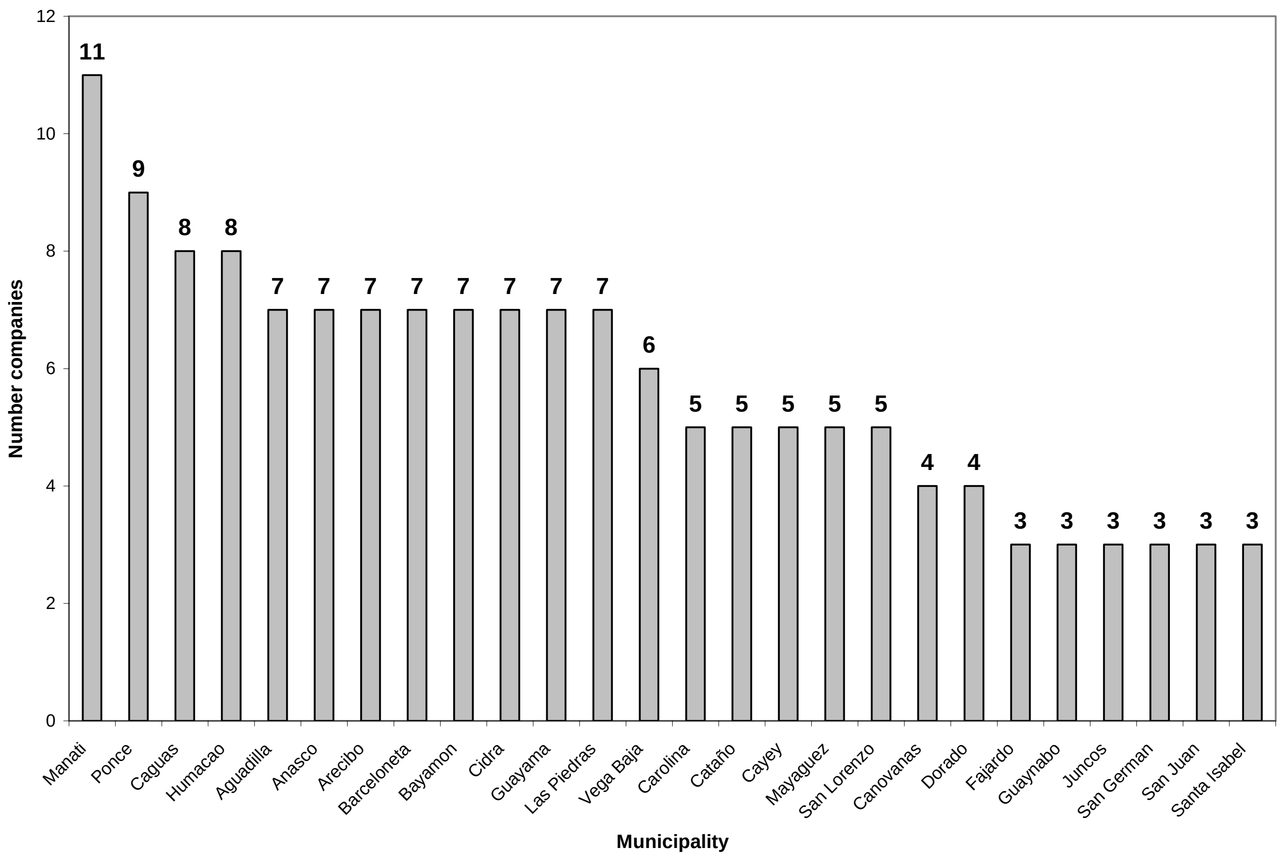


Figure 2 Companies by town

3.5 DESIGN AND VALIDATION OF C&IT ASSESSMENT QUESTIONNAIRE

3.5.1 QUESTIONS FOR THE C&IT ASSESSMENT

This questionnaire, done with collaboration from the graduate committee and industry resources consists of questions focusing on the C&IT assessment and on productivity issues. The complete questionnaire is presented in Appendix 4. The questionnaire used in this thesis is divided in six principal areas:

1. General Company Information – a profile for each company is created including:
    - Company name
    - Contact person
    - Phone number
    - E-mail address:
    - Industrial Sector of the Company
        - i. Chemical & Pharmaceutical
        - ii. Medical Devices
        - iii. Electronics
        - iv. Electro-Mechanical
        - v. Plastics
    - Top three concerns from each company
        - i. Cost competitiveness
        - ii. Quality competitiveness
        - iii. New product introduction
        - iv. New equipment introduction
        - v. Research & development
        - vi. Environmental Health and Safety
        - vii. Other (specify)

2. C&IT Related Questions – This area directly asks the respondent if their company is collecting and reporting real-time data at the factory floor. Following questions depend on their answer to the data collection question:
    - If the company collects real-time data, then they are asked for which areas this information is collected, the types of software and hardware used, and the platforms of data collection available.
        1. These respondents need to answer if the generate real-time reports for their respective areas, what type of reports and which personnel has access to the reports.
    - If the company responds that no real-time data collection is performed, the respondent is asked the reasons why the company does not collect this information.
    - All respondents must answer how motivated are their companies in implementing strategies for real-time data collection.
3. Productivity
    - Respondents where asked to identify the preferred or most relevant productivity measured used in the company
        - i. Gross sales per employee
        - ii. Gross sales per direct labor employee
        - iii. Cost productivity
        - iv. Variance from financial standard
        - v. Multifactor productivity
        - vi. Units per employee
        - vii. Proportional increase in product
        - viii. Other
    - Respondents are also asked to provide the results of the previously mentioned productivity metric for the years 2000 and 2002. The main idea is to compute the percentage of change between these two years to validate our hypothesis that productivity is affected by real time data collection initiatives.
4. C&IT investments

- Respondents where asked if data collection investments where done during the last year and what areas where affected by those investments.
- It was also asked what percent of the budget was assigned to C&IT.

5. Comparison with other plants
    - Respondents where asked if their companies had sister plants – plants belonging to the same parent company where the same or closely similar products are manufactured- and the location where such sister plants where established:
        i. Puerto Rico
        ii. Caribbean
        iii. USA
        iv. Asia
        v. Europe
        vi. Has no sister plants
6. C&IT supplier information
    - In order to identify possible C&IT suppliers the respondents where asked to provide the contact information for their three main suppliers of C&IT solutions.

3.5.2 RELIABILITY AND VALIDITY

Reliability and validity must be assessed to ensure that the questionnaires conclusions are statistically robust. A checklist with reliability and validity criteria is presented in Appendix 3.

3.5.2.1 RELIABILITY

The first step towards a reliable questionnaire is the construction of the questions we want to ask in the study. The main guideline criterion (Appendix 3) is that questions must be written with a simple and understandable vocabulary and that the questions must not be biased with any pre-existent hypothesis. Section 4.1.1 will show the calculation of Cronbach's Alpha to measure reliability.

3.5.2.2 VALIDITY

For the design of the questionnaire, face validity was assessed by having the C&IT team (Dr. Padrón, Dr. Resto, Eng. Cabán from HP and the IT managers for a Medical Devices and a Pharmaceutical industry) evaluate the questionnaire. After the C&IT team gave its feedback, the questionnaire was taken to 2 possible respondents of the questionnaire - in this case IT Managers - . The managers gave suggestions to improve the questionnaire and those suggestions where included in the final Web design. Other suggestions from respondents will be taken into consideration in future C&IT surveys.

3.6 SAMPLE SIZE DEFINITION FOR STUDY

For this step we need to determine the adequate sample size for each of our 5 strata (manufacturing sectors) using stratified sampling. In this technique the population of N units is divided into subpopulations (in this case our strata). With the known strata a sample must be selected from each group. This sample size will depend on the expected proportions for each question of the survey and other statistical considerations.

3.6.1 STRATIFIED RANDOM SAMPLING

The techniques described by Cochran as stratified random sampling where used to determine the number of companies from each sector that should be sampled. The concept of stratified sampling is that a sample size will be obtained from each stratum (group) of data. It is important to determine a sample size that is manageable for the study in terms of companies to respond to the questionnaire and the time required to finish this study. The following steps where performed in order to find the sample size.

Let: $P_h = \frac{A_h}{N_h}$ and $p_h = \frac{a_h}{n_h}$ be the proportions of units in C in the h_{th} stratum and in the stratum, respectively. The random sampling estimate for the whole population proportion is:

$$p_{st} = \sum \frac{N_h \cdot p_h}{N}$$

In our case we wanted to estimate the proportion of companies that will answer a "yes" in question #3 of our assessment (which is presented on Table #4); in other words, which companies will say yes when asked if they where collecting real-time data from the factory floor. This was taken as our most critical question, since the statistical analysis done following the survey will evaluate basically how this real-time data collection effort impact productivity.

In this case the initial presumption was that the p_h for the entire stratum in the sample was the same (p_h =0.5), meaning that for each stratum 50 percent of all respondents will say that they collect real-time data ("Yes" to question #3).

This presumption can be justified by remembering the properties of the equations presented in section 2.4. The equations for the presumed optimum and the proportional allocation techniques are dependent on the proportion p_h; as that proportion nears 0.5 the sample size obtained will be higher (the product (p_h x $(1-p_h)$) will have its maximum value when p_h equals 0.5)

The theory of stratified sampling also mentions that as the proportion of respondents for a specific question alternative nears 0.5; the methods of proportional allocation and optimal allocation will give similar results. Table 3 shows the results of the sample size calculation. The level of confidence for the sample size calculation in this study is 90% and the margin of error was set at 8.0 percent.

Determination of N				
Companies / Sector	Sector	**Ph**	**Qh**	**Wh**
72	pharma & chem	0.5	0.5	0.389189
39	electromech	0.5	0.5	0.210811
35	medical devices	0.5	0.5	0.189189
23	plastics	0.5	0.5	0.124324
16	electronics	0.5	0.5	0.086486
185	Total			
			no	64.15529
			n	47.63587

Table 3 Results from stratified sampling to obtain n

To comply with the proportional allocation sample size, the desired sample was set at 53 companies, with the proportion by sector as defined in Table 3 under the proportional allocation column. Table 4 shows the results of the proportional allocation.

Presumption		*n = 50*	
Proportional Allocation			
72	pharma	19.459	20
39	electromech	10.541	11
35	Medical Devices	9.459	10
23	plastics	6.216	7
16	electronics	4.324	5
185	Total	n'	53

Table 4 Proportional allocation results

3.6.2 RANDOM SELECTION OF COMPANIES

Companies from the five sectors where selected at random to complete the questionnaire [Banks-2001]. If the random variable X is the number assigned to each company in the population, these selected where identified using the equation $X = a + (b - a) * R$ where a is the first company on the lit and b is the last company on the list. The variable R is a random number from the Uniform (0, 1) distribution. The code for the program needed to select the companies is presented in Appendix 2.

3.7 CONTACT THE COMPANIES TO PARTICIPATE IN THE QUESTIONNAIRE

As this thesis is a joint effort with PRIDO; the agency helped us in establishing contacts with the plants. A letter prepared by the head of PRIDCO's Science and Technology Office is presented on Appendix 1. Two strategies were used in the effort to contact PR's industries: direct visit to a few companies followed by remote assistance using the web questionnaire. The direct visits where used in the initial phases of the study to gather feedback on the contents of the questionnaire. These visits also served to test the relevance of the questions to the companies and to verify if the objectives to reliability and validity where being accomplished with the way the questions where written.

Once the questionnaire was tested with a few companies the remaining companies where contacted by phone. The contact person to respond the questionnaire was identified. Typical questionnaire respondents where the Information Technology Manager and the Engineering Manager. After the contact person was identified, information was stored; a username and password where provided for each user. The user had to login to the web page: **http://136.145.151.203/pridco/login.aspx** where he/she used the username and password to gain access to the questionnaire. The details for the web-page creation are described in the next section.

3.8 PROGRAM THE C&IT ASSESSMENT QUESTIONNAIRE ON THE WEB

The C&IT assessment questionnaire was published on the World Wide Web using Microsoft tools such as Visual Studio.Net[1] ® and other Web-Publishing applications. This web page had to be carefully developed for ease of use. The creation of the questionnaire consists of the user interface (in this case the web page) and the underlying database where the user information is stored. Both aspects are described in the next sections. Appendixes 6 and 7 will show some of the basic code and charts used in the design.

3.8.1 WEB PAGE DESIGN

As explained earlier the C&IT assessment was published on the web using Visual Studio.Net. The web questionnaire contains a total of 29 web forms: three are basically informational pages ("**Login**", "**Instructions**" and "**Thank You**" pages) and the others are the 26 questions on the assessment. Questions are the same for all users, except for questions 11 and 15 that are modified for the chemical & pharmaceutical industry to include processes relevant to them. Figure 3 presents a snapshot of the login page; the other pages of the questionnaire have the similar structure and background.

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[1] Visual Studio.Net is a product of Microsoft Corporation

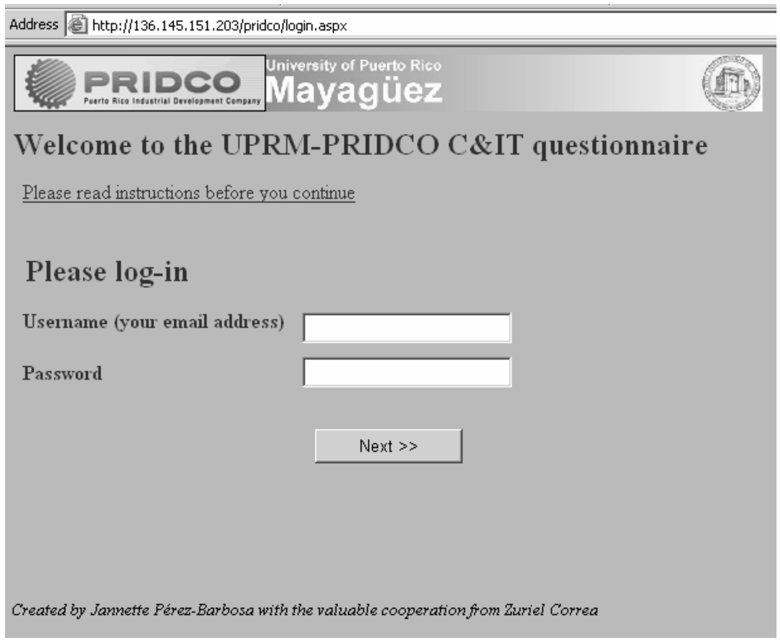


Figure 3 A snapshot of the login page

For the Login page it is important to remember that an important aspect of this assessment is the security of the information of the companies. This page requires that respondents of the assessment obtain the login and password information from the researcher. Unauthorized users do not have access to the questionnaire.

For the 26 questions as well, a certain organization is enforced. Questions that have radio o list items must be answered; if a response in not made, the page will refresh itself until an answer is given. This way, the study reduced the possibility of respondents skipping questions that might affect the resolution of the survey.

It is also important to comment that this questionnaire is dynamically designed; as a user responds to a question, the answers are stored and the next set of questions is determined depending on previous responses. Figure 4 presents a snapshot for a question in the survey. Components like option boxes and text boxes are use to minimize the chance of error of respondents.

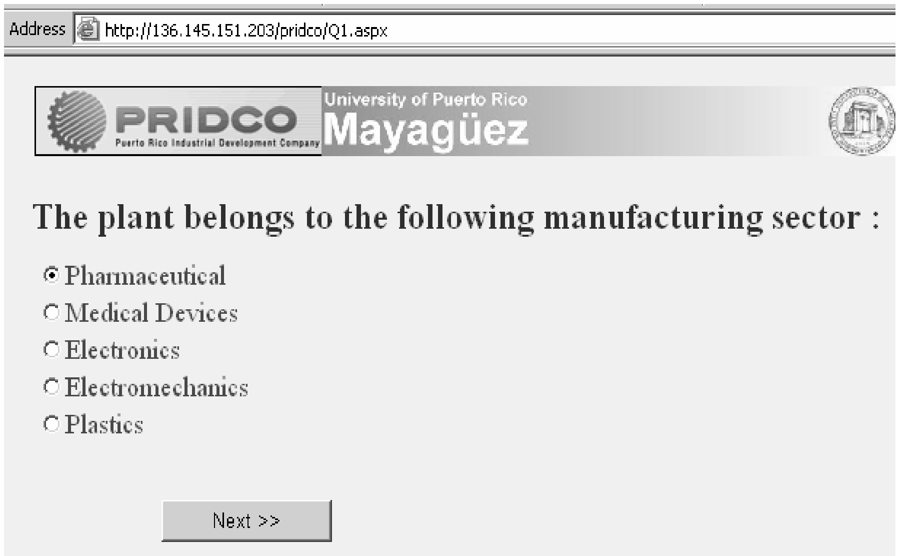


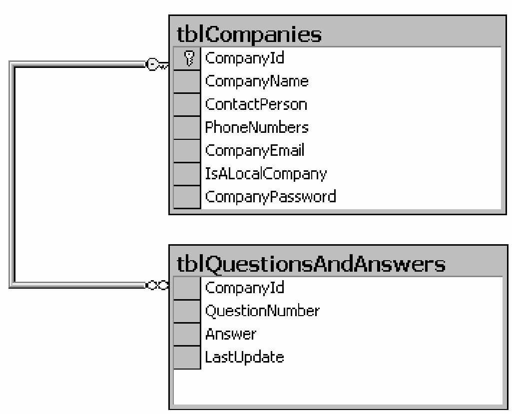
Figure 4 A snapshots for a question on the assessment

Since the web page was constructed with Visual Studio; code in Visual Basic as well as HTML (***Hypertext markup language***) statements are used. Some necessary coding to link the web pages to the database is done in ASP.net. Once the web page was completed it was published in the UPR-Industrial Engineering department server.

3.8.2 DATABASE DESIGN

In designing the databases it is important that response fields are well identified. For this questionnaire two tables were defined: these were named tblCompanies and tblQuestionsAndAnswers. The table named tblCompanies was used as a registry of the contact information for each company. Its main purpose was to store basic contact information from each company. The relationship diagrams for these tables are showed in the Figure 5.

Figure 5 Relationship Diagram



The fields included in this table and their data types are showed in Figure 6.

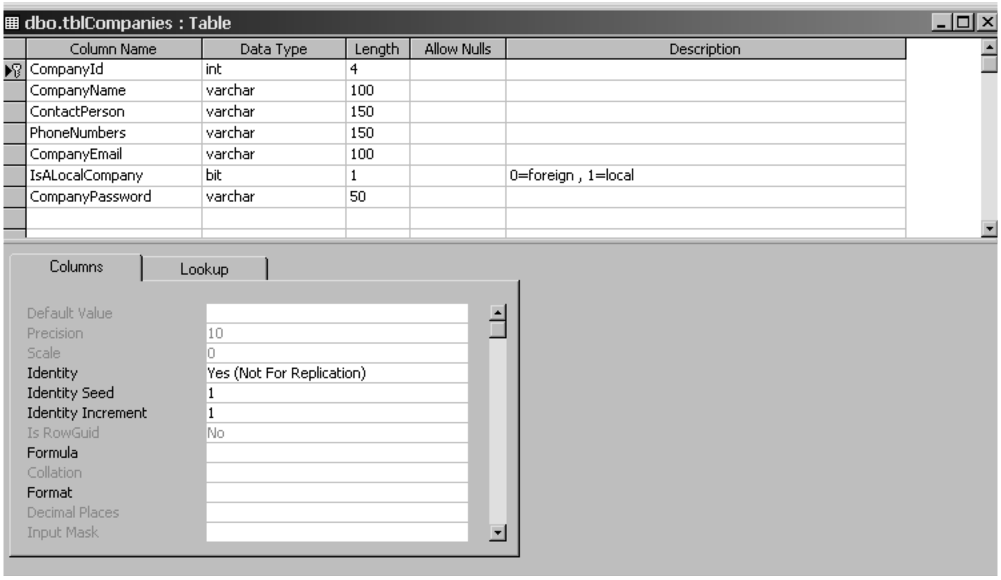


Figure 6 Design view for tblCompanies

It can be seen that tblCompanies includes the fields to perform the login for each individual user. The fields required to make this login are the ones named “Company Email” as the username and “Company Password” as the unique company password.

Another important aspect of tblCompanies is that it contains a primary key. Each table should include a field or set of fields that uniquely identifies each record stored in the table. This information is called the primary key of the table. Once a primary key is designated for a table, the Database Management System (in this case SQL Server) will prevent any duplicate or null values from being entered in the primary key fields. The primary key is also the link between the two tables. As can be seen in Figure 7, the field “CompanyId” is one of the fields in tblQuestionsAndAnswers. The other fields for this table include “QuestionNumber”, “Answer” and “LastUpdate”. A record in this table will include which company answers a specific question, the answer to this question and the specific time in which it was answered. These records will then be further analyzed.

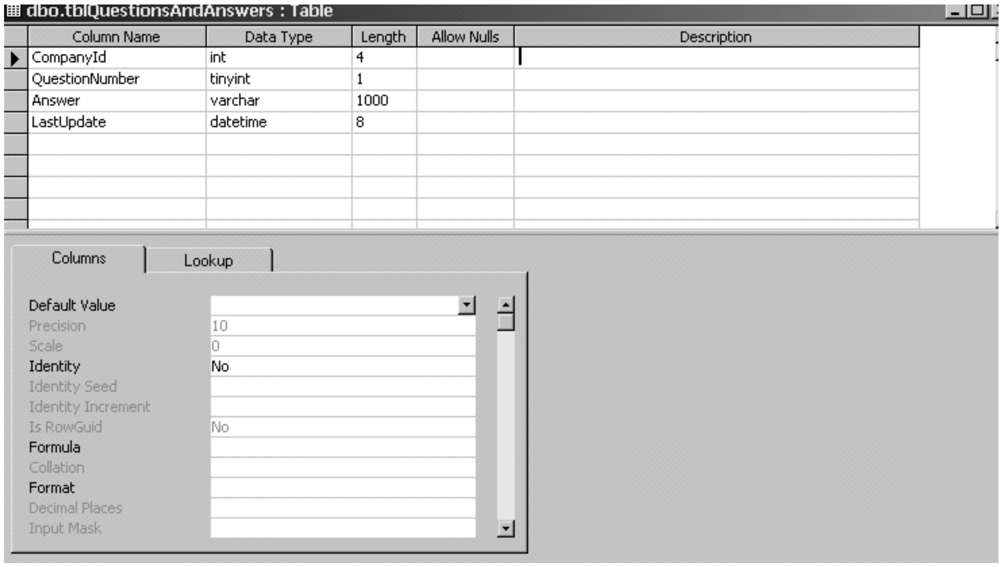


Figure 7 Design view for tblQuestionsAndAnswers

3.9 INDUSTRY CONTACTS TO EXPLAIN QUESTIONNAIRE AND RESEARCH PURPOSE

With the established contacts in Section 3.1.5 and the questionnaire published on the Web; site visits and telephone conferences where performed to explain this work and its implications and to give a brief orientation on how to answer the questionnaire. Also, any doubts about confidentiality and management of the information where answered.

The initial phase was to visit a small sample of companies (3 to 5) to receive feedback on the questionnaire and comment on suggestions for improvement. This first visits where used to assess the reliability of the questionnaire and eliminate ambiguous wording.

Once the fine-tuning was done; the process to obtain the responded from the company contacted was the following:

- Find a key contact in the desired company (typically IT or Engineering manager)
- Explain the purposes and implications of the questionnaire
- Email the questionnaire in PDF form (since it was desired that the respondent shared the questionnaire with critical stakeholders inside his/her company)

- Create and send a username and password
- Set a conference of visit (if necessary)
- Do follow-up until the respondent's questionnaire appeared in the database
- Send some additional questions validate previous answers to specific questions
- Additional follow-up to this validation questions when needed

The system by which this assessment was performed was accepted by all the companies sampled. The follow-up calls and served to clarify doubts the respondents had regarding the question contents or the data that had to be provided.

3.10 RESPONSE COLLECTION FROM THE WEB PAGE

The data collection process started during the month of December 2003 and extended until April 2004. The data collection process went relatively smooth with a period on which the web page was under continuous improvement. As the data collection process geared to its end the problems where corrected and the information was successfully collected. The data supplied by the companies was stored in the SQL Server (SQL – ***Structured Query Language***) database named "PRIDCO". The information was revised and updated on a daily basis.

3.11 STATISTICAL ANALYSIS OF INFORMATION ON DATABASE

As data obtained from the database was stratified and analyzed by in various ways. Results to be discussed include:

- General company information
- C&IT related
- Productivity related
- C&IT investment
- C&IT suppliers

Critical results concerning C&IT and productivity are presented and analyzed using descriptive statistic tools such as Paretos, plots, histograms, etc. These include:

- Responses by sector
- Companies top concerns
- Real-time data collection
- Real-time reporting
- Productivity metrics in use
- Productivity performance in 2000 and 2002
- Sister plants
- Suppliers identified

3.12 CONCLUSIONS AND RECOMMENDATIONS FROM THIS RESEARCH

Conclusions and recommendations are presented with the analysis of the questionnaire in the areas of C&IT and productivity. A final analysis for this project has been presented to PRIDCO. The analysis and conclusions are presented below.

CHAPTER 4 - QUESTIONNAIRE ANALYSIS

This chapter will discuss the findings of the Communication and Information Technology Questionnaire. The evaluation of the robustness of the questionnaire will be discussed, followed by critical discussions of the critical findings from the assessment.

4.1 BASIC STATISTICS

Out of 53 companies identified, 52 responded the questionnaire. The totals per sector are: 21 chemical & pharmaceutical, 10 medical devices, 9 electromechanics, 7 plastic and 5 from electronic. Figure 8 describes the sample.

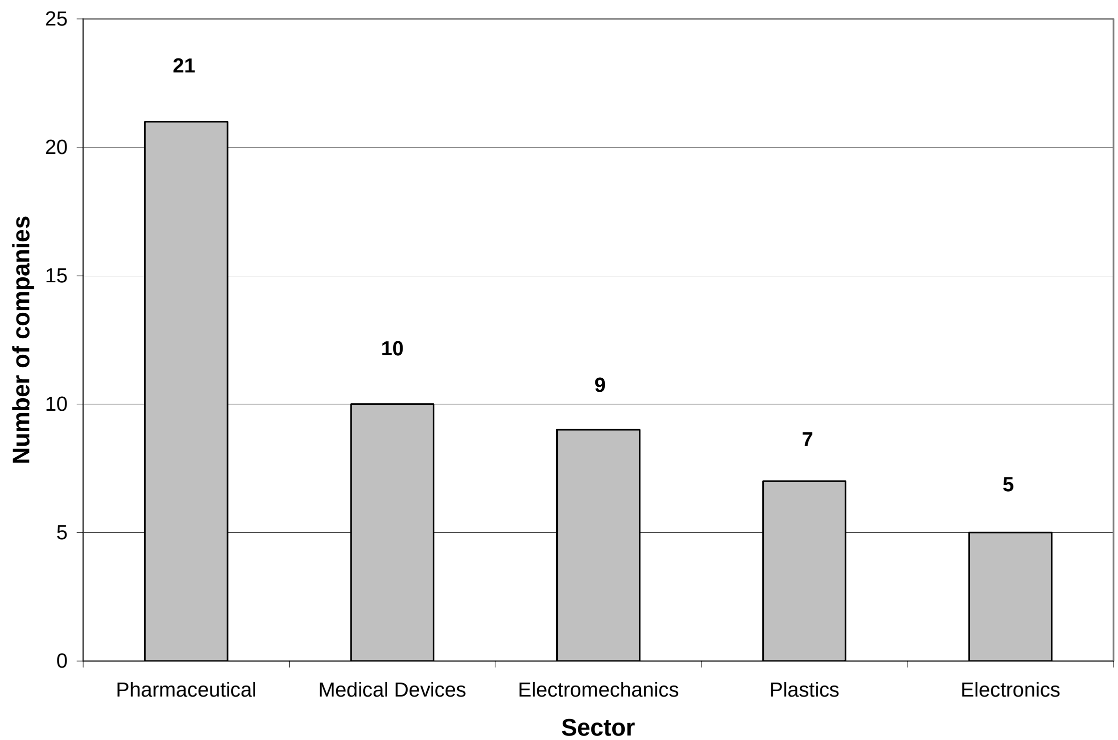


Figure 8 Companies that answered the questionnaire

4.1.1 RELIABILITY

Reliability can be viewed as the consistency of the responses on a survey. With reliable questionnaires respondents consistently understand and answer the questions similarly each time they have the opportunity. One measure than can be used to evaluate reliability is Cronbach's Alpha. This measures how well a set of variables measures a concept. With this tool it is possible to measure the internal consistency of a questionnaire.

For this questionnaire, the consistency of the respondents was evaluated re-testing **18** of the 52 respondents. They responded again the question about data collection on the shop floor. In this case, this question was expanded with an explanation on how the data is being collected to clarify the meaning of real-time.

Of the 18 companies sampled, 17 answered "yes" to collecting real-time data in the shop floor. Five of the 17 changed their answers after re-testing and further discussion with the researcher. Cronbach's Alpha statistic was **77.69%**; from which it can be concluded that the questionnaire is reliable. Appendix 5 shows the calculation of the Cronbach's Alpha.

4.1.2 VALIDITY

As explained in chapter 3 face validity was assessed by having the C&IT Team (Dr. Padrón, Dr. Resto, Eng. Cabán and the IT managers for a Medical Devices and a Pharmaceutical industry) evaluate each question. The questionnaire was also taken to PRIDCO to evaluate if questions complied with PRIDCO's needs for information about Puerto Rico's industries. A more detailed validation of the assessment will be done for future efforts, using the current questionnaire as a starting point.

4.1.3 RESPONSE RATE

The response rate was divided by sectors and then calculated for the whole sample. The values are presented in the following table.

Table 5 Response Rate

Sector	Desired Sample	Responses	Response Rate
Pharmaceutical	20	21	105%
Medical Devices	10	10	100%
Electromechanics	11	9	82%
Plastics	7	7	100%
Electronics	5	5	100%
Total	53	52	98%

The sector where the response rate is the lowest is in electromechanics. To compensate the lack of response from two electromechanical companies in the global sample, an additional pharmaceutical plant was contacted. One of the reasons that might allow the response rate to reach such high values might be the web-based approach and the follow-up through the phone and email.

4.2 QUESTIONNAIRE RESULTS

The results for the questionnaire will be divided by the section of the questionnaire and then by question.

4.2.1 REAL-TIME DATA COLLECTION

This section included questions from 1 to 6 in the C&IT questionnaire. It looks for company concerns, which companies collect real-time data, the areas of real-time data collection and the motivation to collect real-time data

4.2.1.1 COMPANY CONCERNS

Respondents of the survey where asked which where their top concerns for their business. The list of concerns included:

- Cost competitiveness
- Quality competitiveness

- New product introduction
- New equipment introduction
- Research & development
- Environmental, health and safety

The respondents where also asked to add any additional concerns that may be of their interests. The following chart will summarize the companies' top concerns.

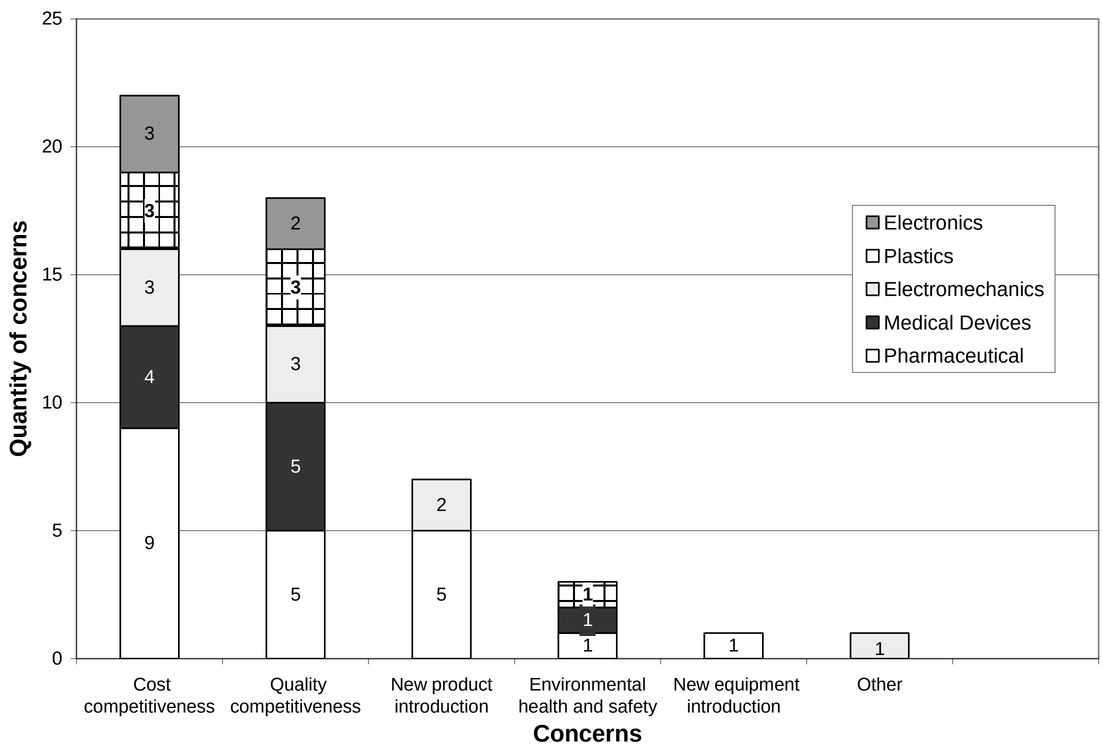


Figure 9 Companies top concerns (52 responses)

It can be seen that most of the concerns for all manufacturing sectors are from the cost and quality areas. As it is well known, the world-wide economic situation makes it imperative for businesses to maintain its cost competitiveness. Another critical concern for all businesses is the quality competitiveness. The globalization of the economy makes businesses aware that quality is more than ever an issue critical to the companies' survival. It is important to note that all sectors are well represented in the main concerns.

4.2.1.2 C&IT DATA COLLECTION AND REPORTING

Respondents where asked if their companies collected and reported real-time data on the shop floor (Questions 3 and 7 of the questionnaire). Together, real-time data collection and reporting, are seen as an enabler to productivity. Depending on the response given, more questions with emphasis in the area where asked. Figure 10 presents the total breakdown (Yes vs. No) while Figure 11 presents the breakdown by sector when questions 3 and 7 are combined in a chart.

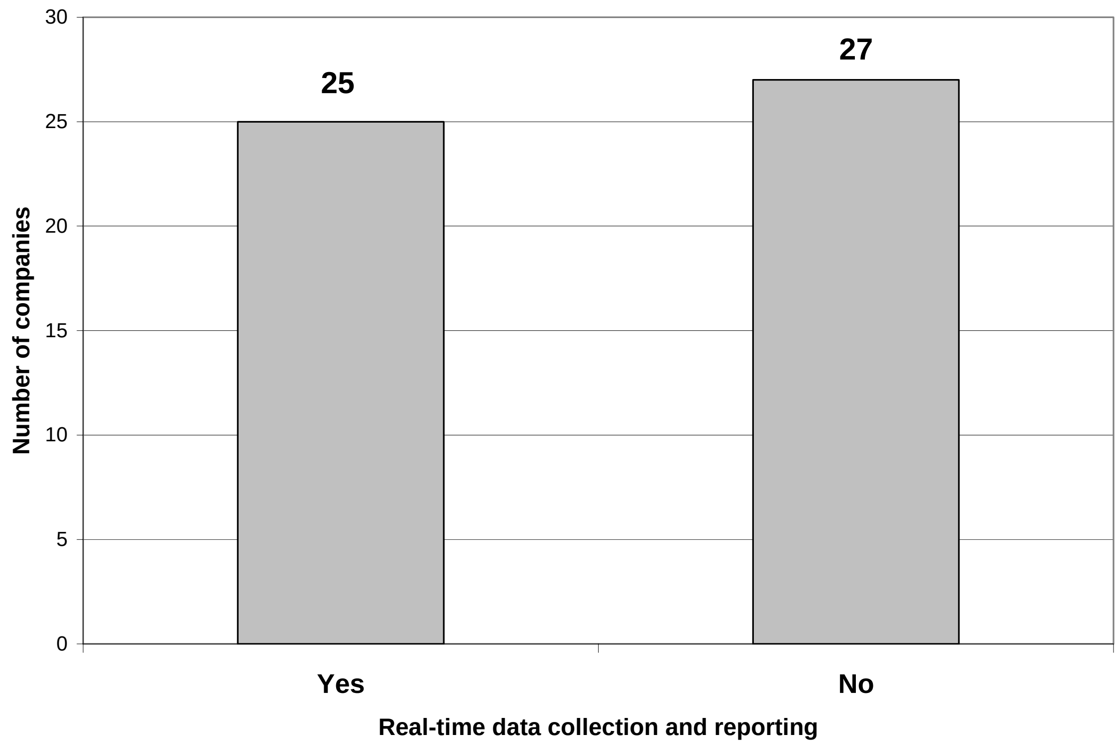


Figure 10 Real-time data collection and reporting

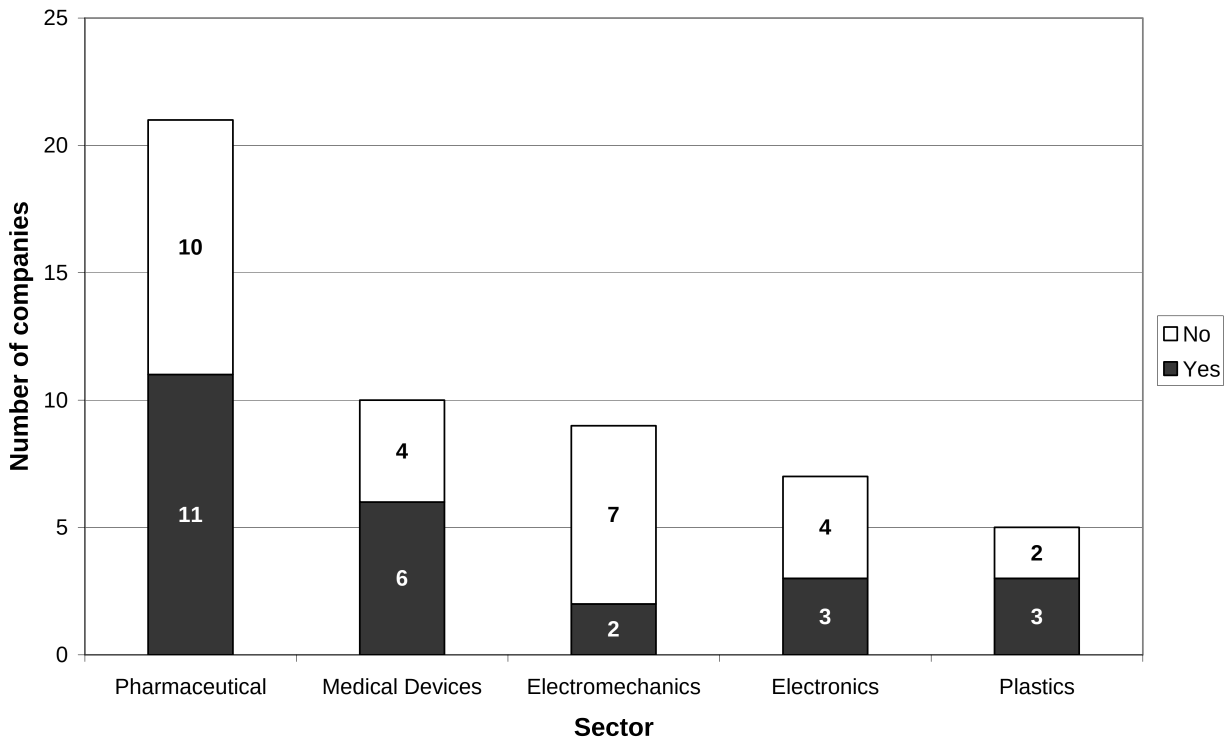


Figure 11 Real-time data collection and reporting per sector

Figure 10 shows that just over 48% (25 of 52) of companies collect real-time data in one of more processes of the shop floor level. From Figure 11 it is observed that the percentage responding affirmatively varies per sector, with electromechanics being the sector with lower real-time data collection and reporting activity.

Another analysis performed was the calculation of a confidence interval to determine if significant differences are present between the proportion of companies that collect and report real time data versus the companies that do not have these capabilities. The confidence interval for the proportion of companies that collect and report real time data is **[0.345 , 0.617]** and the interval for those that don't is **[0.383 , 0.685]**. Since the intervals overlap, it can be concluded that the two proportions do not differ. This evidences a clear area for opportunity, as roughly 50% of the surveyed companies do not have in place a system for data collection and reporting.

4.2.1.3 AREAS WHERE C&IT DATA IS COLLECTED

Respondents that do collect real-time data in the shop floor where asked in which areas was the data being collected. The alternatives given for this question where:

- Planned versus actual production
- Product tracking through the shop floor
- Quality problems (defects, rejects)
- Equipment details (downtime, starvation, blockages)
- Maintenance/part replacement activity

The respondents were also given the opportunity to add any other important areas where data is collected. Figure 12 summarizes these results. Quality data collection was the top concern, followed by product tracking, downtime and maintenance.

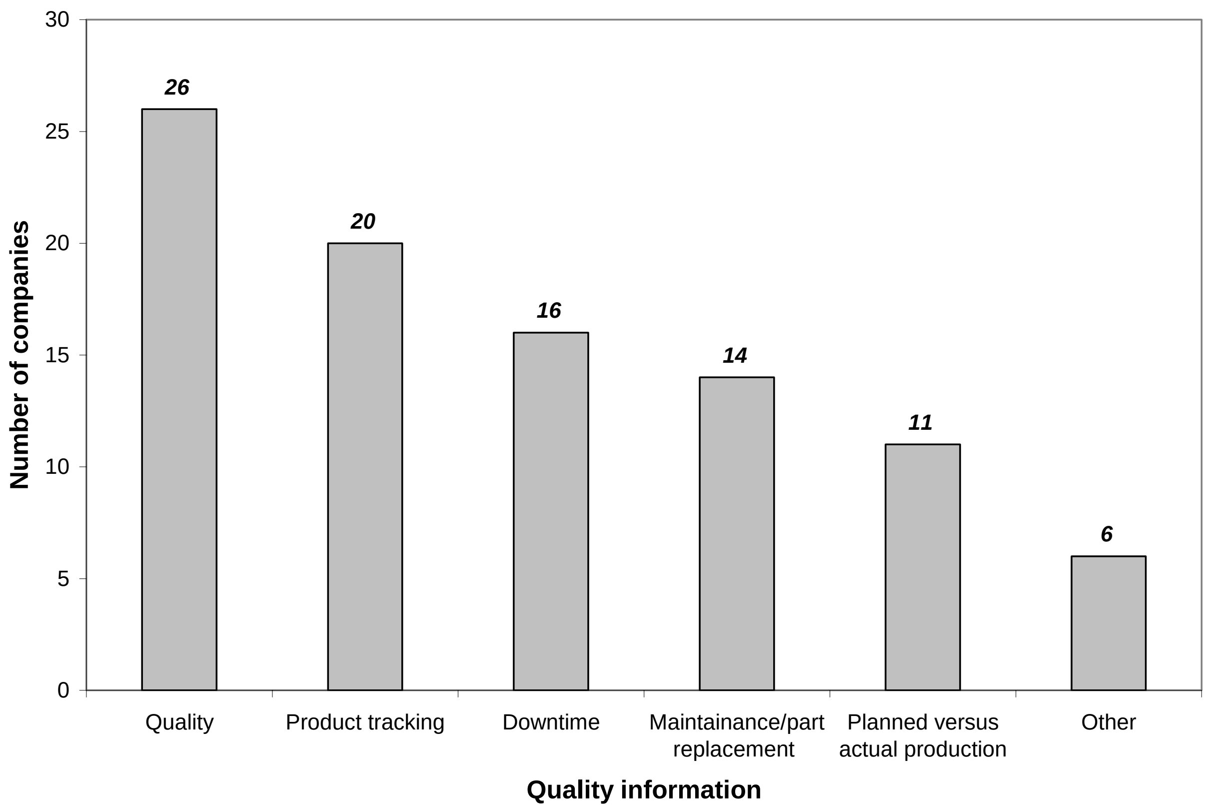


Figure 12 Areas where real-time data collection is present

As with the previous questions, the data collected by all sectors is quite similar; i.e.: a specific sector does not collect more quality data than another sector. The following chart explains the data collection per each sector

The breakdown by sector (Figure 13) also shows that all sectors share the same concerns in terms of data collection.

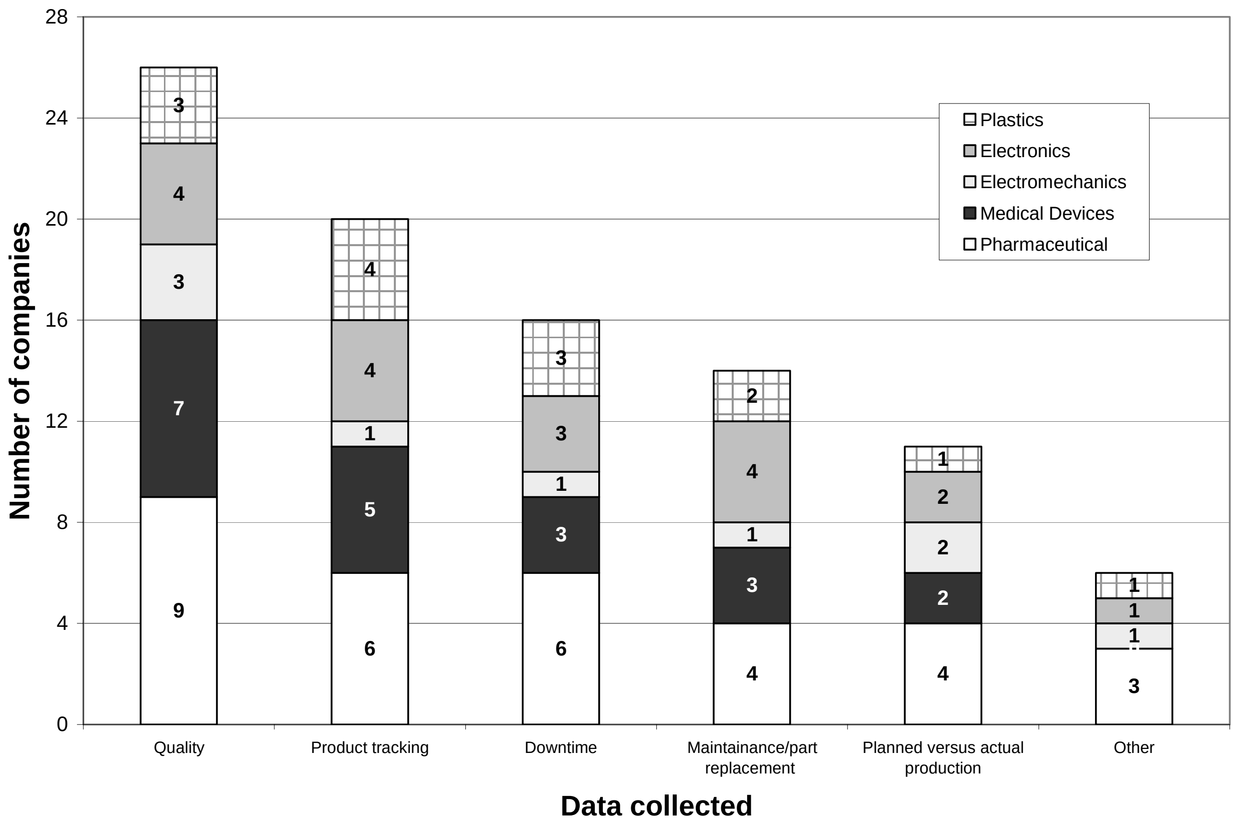


Figure 13 Areas where real-time data collection is present per sector

4.2.1.4 REASONS FOR NOT COLLECTING REAL-TIME DATA

For this question, we asked all 23 respondents what indicated that no real-time data collecting is done at their companies to describe the reasons why there is no real-time data collection. Some of the alternatives where:

- Equipment acquisition cost
- System maintenance cost

- Lack of expertise within the plant
- Communication infrastructure acquisition cost
- Lack of support from corporate office
- Regulatory and validation concerns

The following chart shows why data collection systems are not present in those 23 plants.

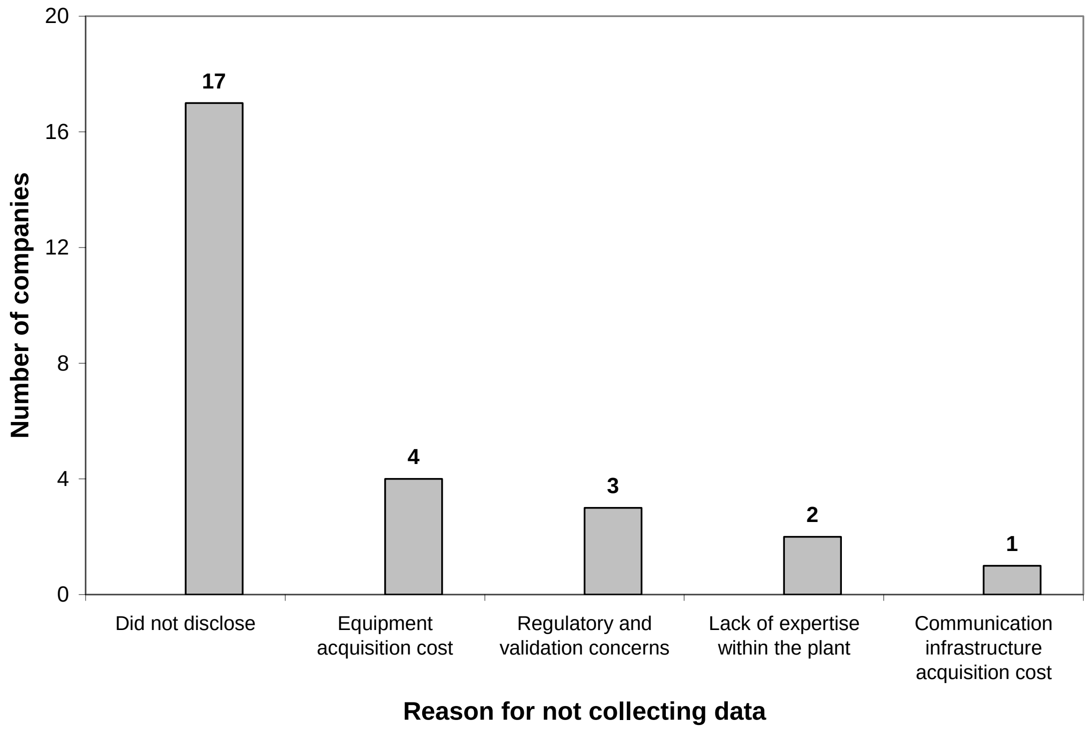


Figure 14 Reasons for not collecting real-time shop floor data

We can see from Figure 14 that most of the respondents to this question did not disclose the reasons.

4.2.1.5 INTEREST IN COLLECTING REAL-TIME DATA

Another important question for our respondents was their interest in real-time data collection solutions. This question was made to all 52 respondents to assess both companies with some data collection and those with no data collection. For those with no data collection they could express their interest (if any) in this subject. For those companies with some data collection this was the opportunity to express their business interest of more of these solutions. Most companies (48 of 52) express their interest in implementation, with almost 60% ready for immediate implementation. Figure 15 presents these findings.

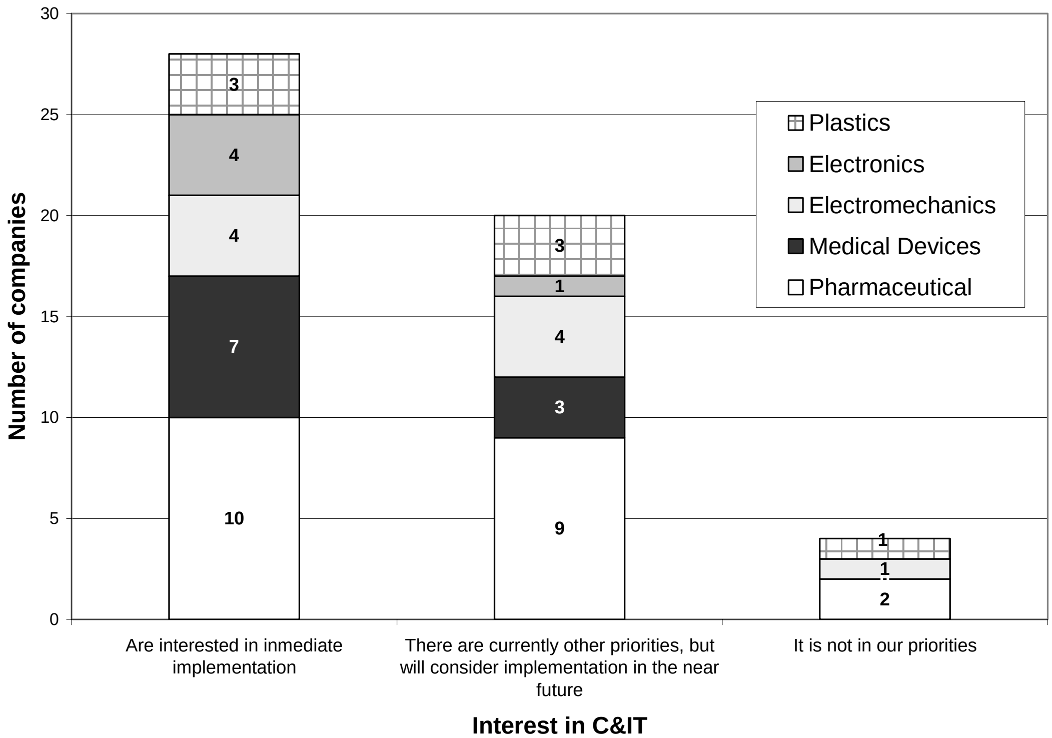


Figure 15 Real-time data collection interest

We wanted to get a more in-depth analysis of this question to assess if companies with no real-time data collection where more eager to implement real-time data collection solutions than those with some real-time data collection. It was surprising to see that companies with some real-time data collection showed more interest. For companies with no real-time data collection, most respondents answered that they had another priorities. (see Tables 6 and 7)

Table 6 Interest in implementing C&IT solutions - Companies that already have C&IT

Answer	Times	Percentage
Are interested in immediate implementation	20	68.97%
There are currently other priorities, but will consider implementation in the near future	9	31.03%
It is not in our priorities	0	0.00%
Total	29	100%

Table 7 Interest in implementing C&IT solutions - Companies that don't have C&IT

Answer	Times	Percentage
Are interested in immediate implementation	8	34.78%
There are currently other priorities, but will consider implementation in the near future	11	47.83%
It is not in our priorities	4	17.39%
Total	23	100%

4.2.2 REAL-TIME REPORTING

Another important question for those companies that collect real-time data is the use that is given to that information. If the information from the companies is just collected and not used then it is just as if no data is collected. Real-time reporting by sector is presented in Figure 16. The graph identifies the companies that collect and report real time data with a “Yes” and the companies that just collect real time data with a “No”.

Real-time data collection and reporting go together to rip the benefits from the investments. That is why the emphasis in the combination! Figure 17 shows a chart of the companies that collect some real-time data in the whole sample.

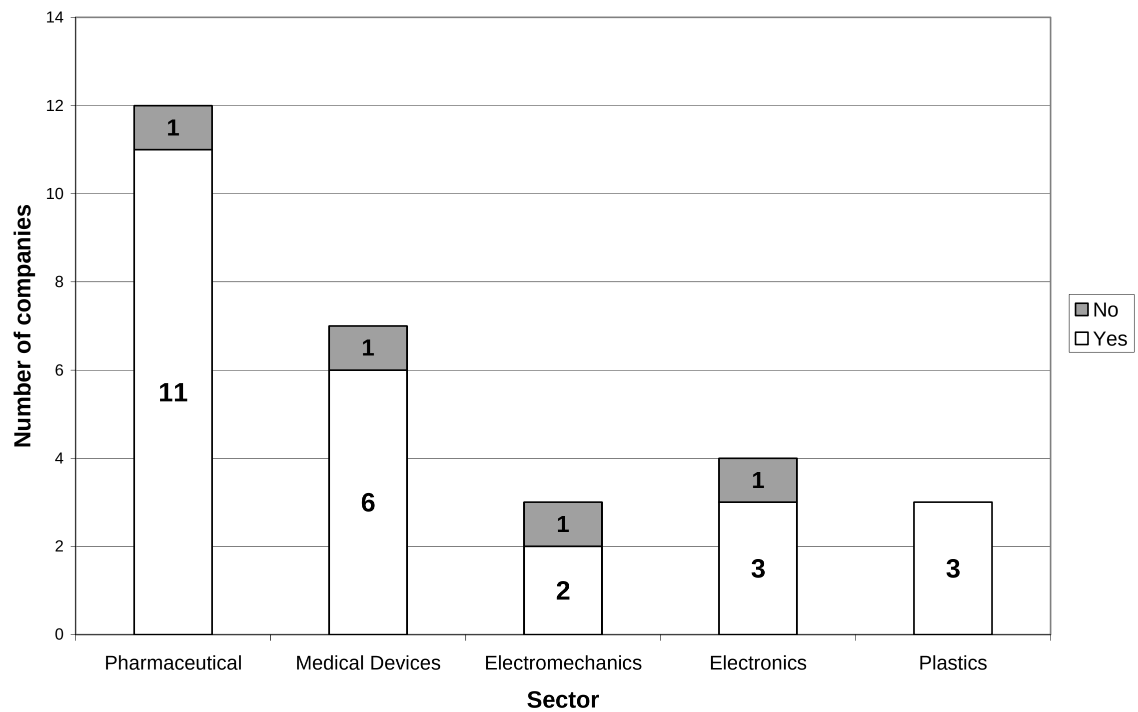


Figure 16 Real-time reporting

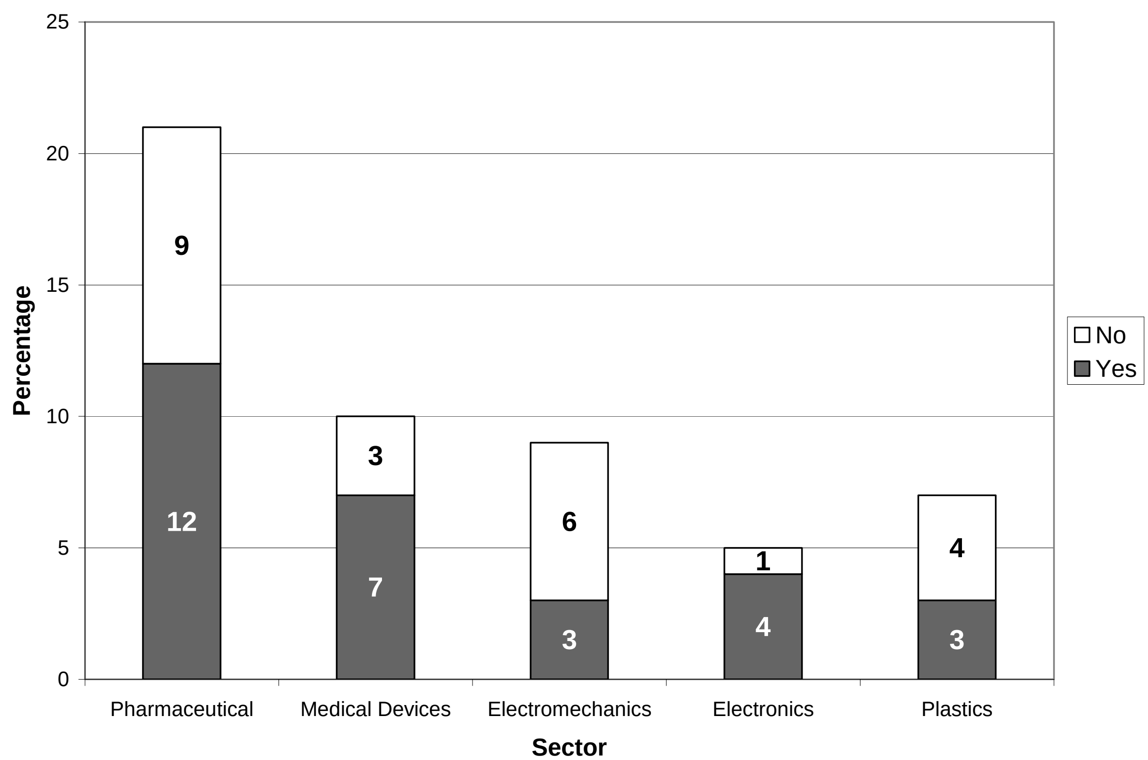


Figure 17 Real-time data collection

4.2.2.1 REAL-TIME REPORTS GENERATED

For those companies that generated real-time report from the data collected at the shop-floor it was asked what types of reports where generated. The respondents had the following alternatives to select from:

- Defect/reject counts per period for a sample of production
- Defect/reject counts per period for 100% of production
- Product current location by means of serial/part number
- Downtime trends
- Other (please specify)
- Downtime contributors
- Hourly trend with quality warnings
- Current vs. Planned with hourly trend

They where also asked for any other report not listed in the questionnaire. The response could include one or more of these reports used at the factory floor. Figure 18 summarizes the responses.

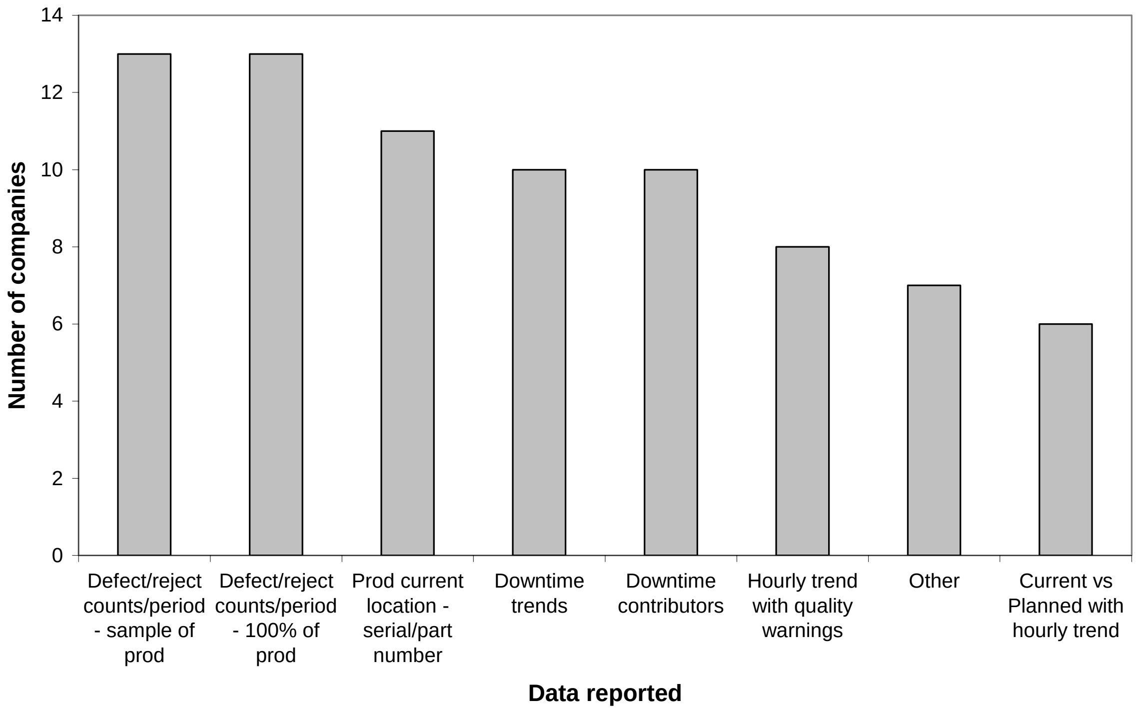


Figure 18 Real-time data reported

This question reflects again that most of the information collected and used concerns quality and product tracking in the shop floor. Most of the information is related to the concerns expressed by the companies in these same areas. Some information is also collected on downtime.

4.2.2.2 REAL-TIME REPORT ACCESS

The next question looked for the users of the reports generated. The most important finding in this issue was that line employees are second to last in this Pareto (see Figure 19). The importance of this finding is that responses to issues in the line might be slow if the operators that are performing the task – and the ones that are closest to the process – can not get timely information of the shop-floor.

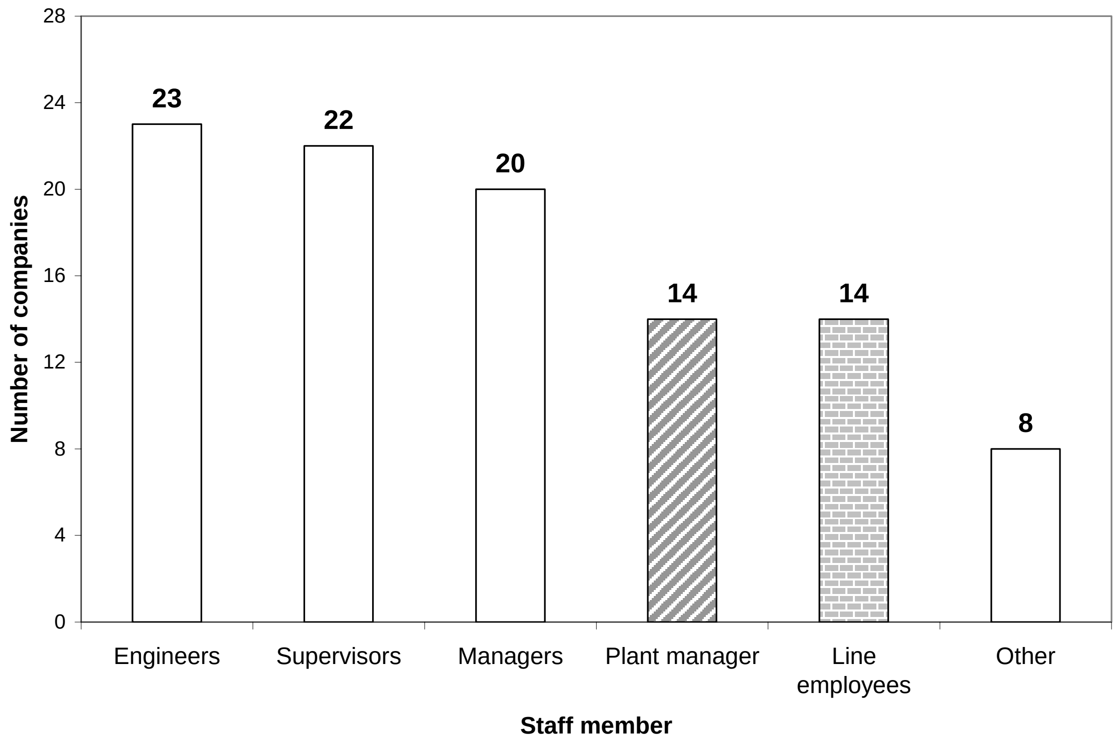


Figure 19 Access to real-time reports

4.2.3 REAL TIME DATA COLLECTION INFRASTRUCTURE

For a real-time data collection system to function properly there is a basic infrastructure that will allow the collection, storage and reporting of the data. This includes software and hardware that must perform the desired functions.

The first element that will be covered is the communication infrastructure; i.e. the equipment was used to transmit the data. Some of this equipment can be wired (wide area local network, wide area network) or wireless (wireless local area network). As you can see in Figure 20 the most used infrastructure is the wired area local network

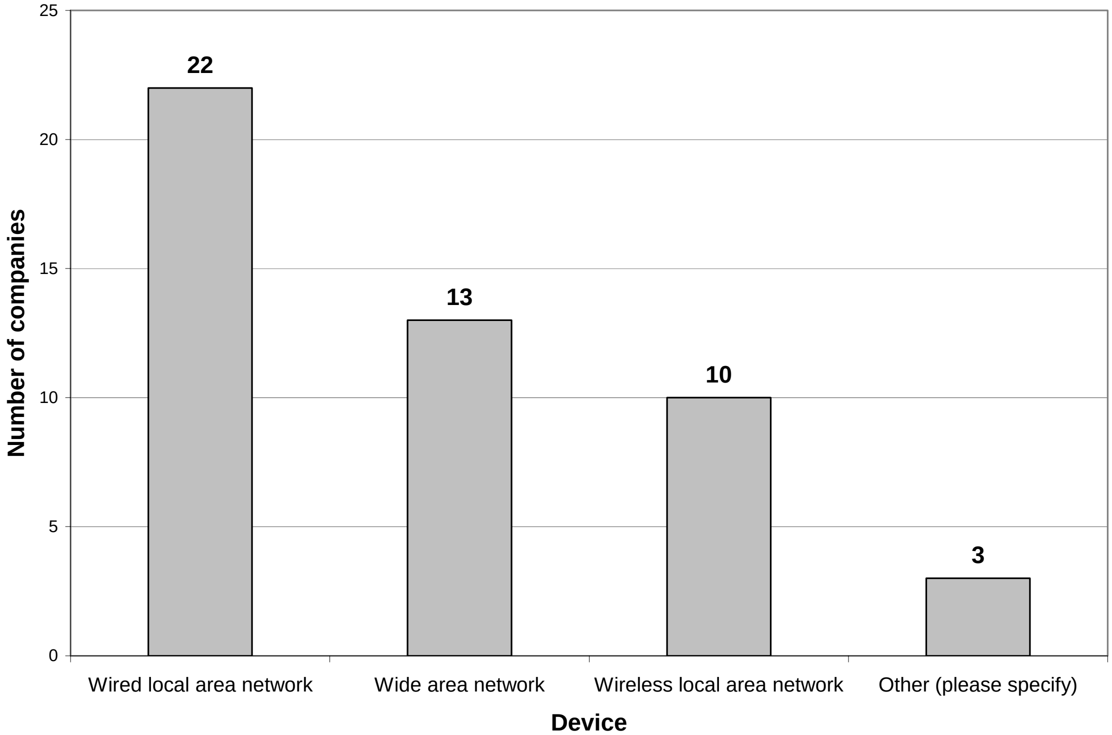


Figure 20 Communication Infrastructures

The second element of the infrastructure is the hardware platform. Figure 21 shows that the preferred platforms are PC's and servers, followed closely by programmable logic controllers. The use of PLC's as a data collection platform allows data collection systems to integrate more or one process variables of a system and to program more responses by the use of sensors. This data is eventually stored in a database.

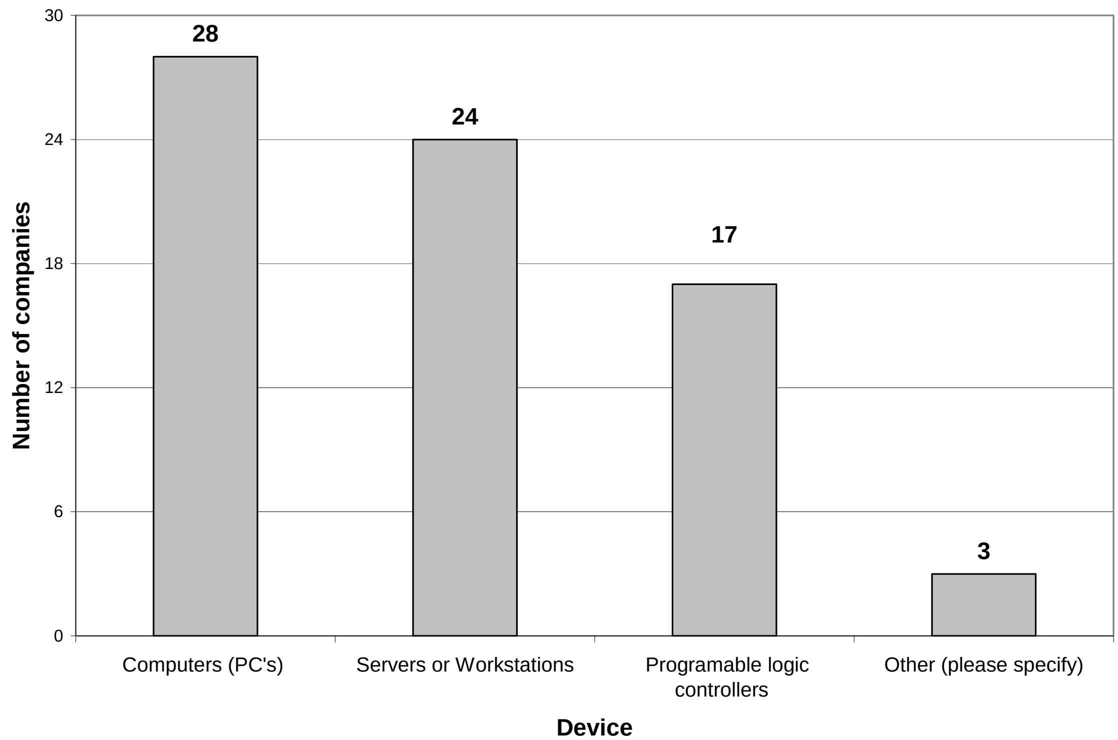


Figure 21 Data collection platforms

For those companies that indicated the use of PC's we wanted to know which operating systems where used. The huge majority of respondents use Microsoft Windows, with a few respondents using other alternatives. (See Figure 22)

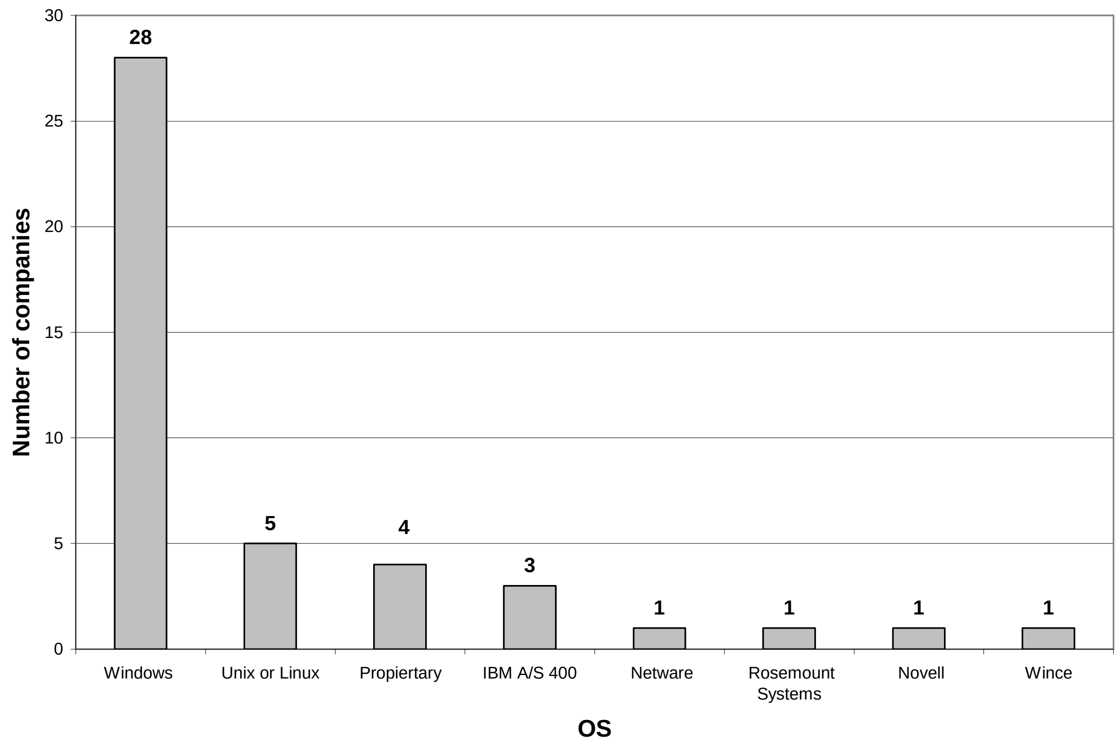


Figure 22 Operating Systems

Once the data is collected it is important to ask where it is stored. The database management system (DBMS) in use must have the capability to support the real-time data activities. Figure 23 shows the database systems used by the companies in the survey.

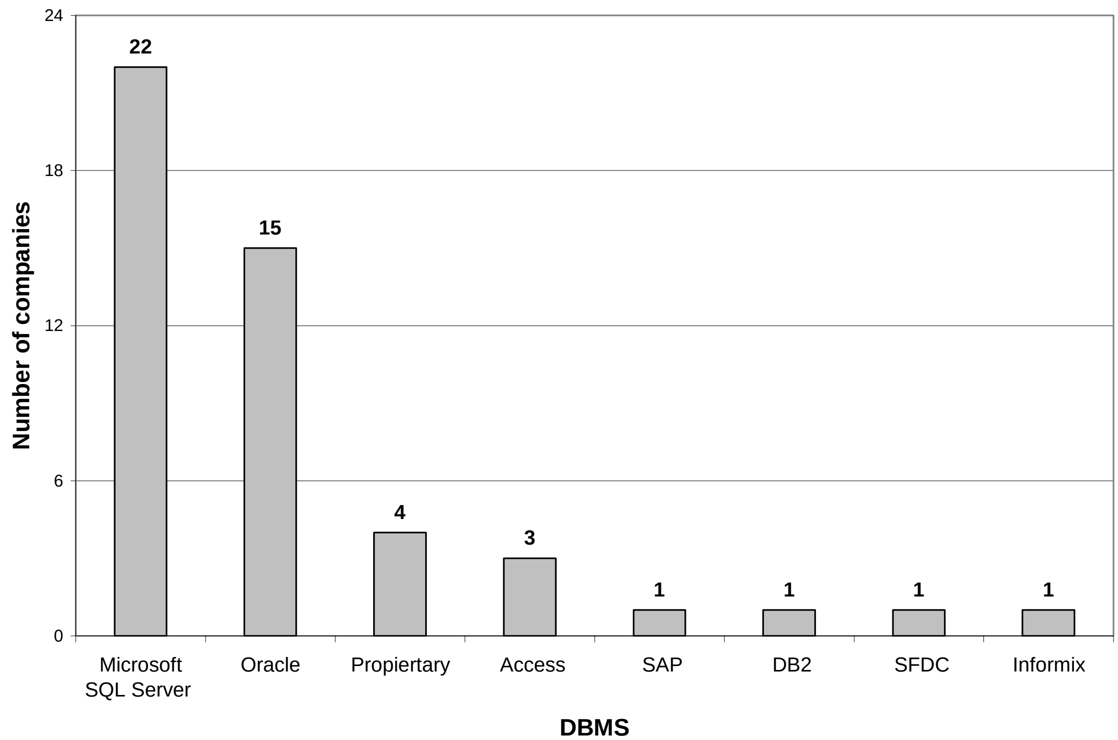


Figure 23 Database systems

Most companies use Microsoft SQL server and Oracle. Some companies responded that their companies used proprietary DBMS and only a few indicated the use of Microsoft Access. In future assessments a key question might look at the DBMS expertise available in the companies.

4.2.4 SISTER PLANT ASESSMENT

Another key question in the study was the existence of sister plants. A sister plant can be defined as a company with the same that makes a comparable product to the company surveyed. The comparison with sister plants eases the task of benchmarking on competitiveness measures. It also provides an opportunity on comparing on C&IT investment and its possible impact on productivity. Figure 24 summarizes the location of sister plants.

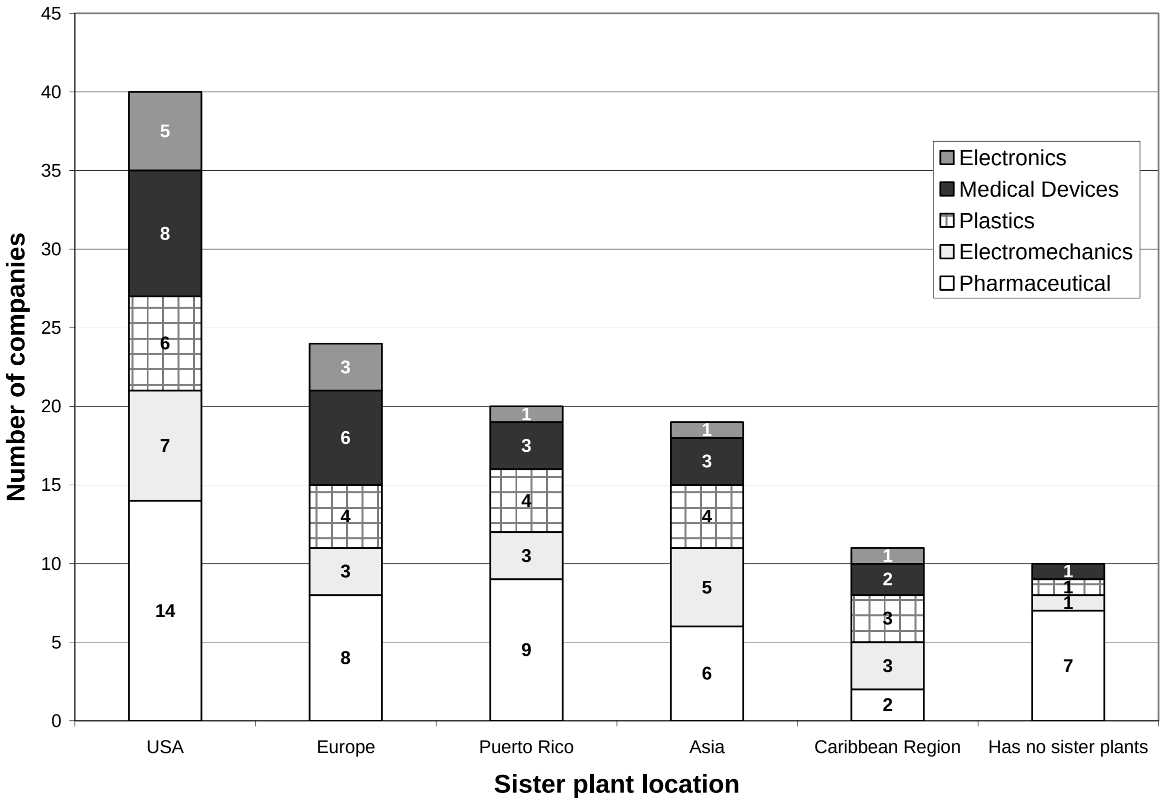


Figure 24 Location of sister plants

It can be seen that over 80% of the companies (42 out of 52) have sister plants, with the US being the most common location. For those companies that have sister plants we wanted to evaluate how the sister plants compare with respect to C&IT implementation. Figure 25 presents how does the responding plant compare to sister plants.

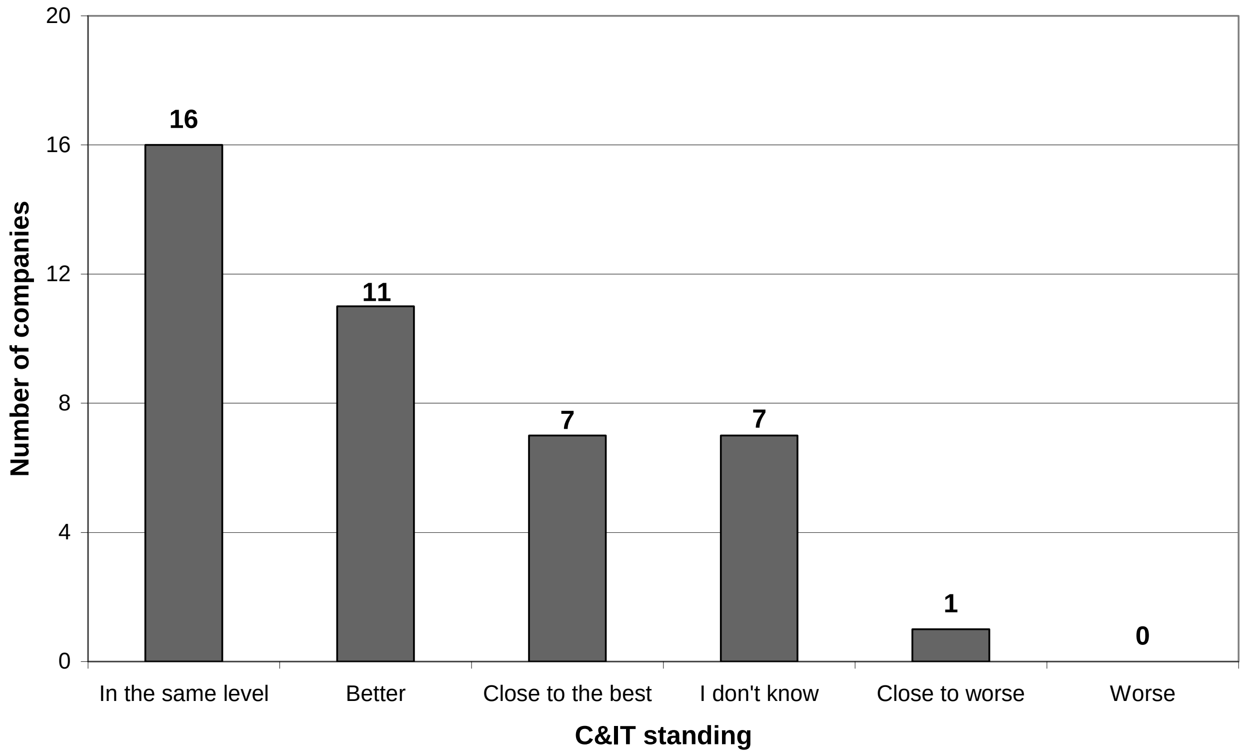


Figure 25 Comparison with sister plants about C&IT

Close to 65% of the plants (27 of 42) sampled believe that their C&IT strategies are at least at the same level as the sister plants. Future work could consider making the assessment available to local and sister plants to start developing reliable global benchmarks.

4.2.5 C&IT INVESTMENTS

Another important issue to collect from the responding companies pertain to C&IT investments. Over 70% of respondents indicated that C&IT purchases were made during the last year (refer to Figure 26). A future activity in understanding the relation between C&IT deployment and productivity is to obtain information on the yearly dollar investment.

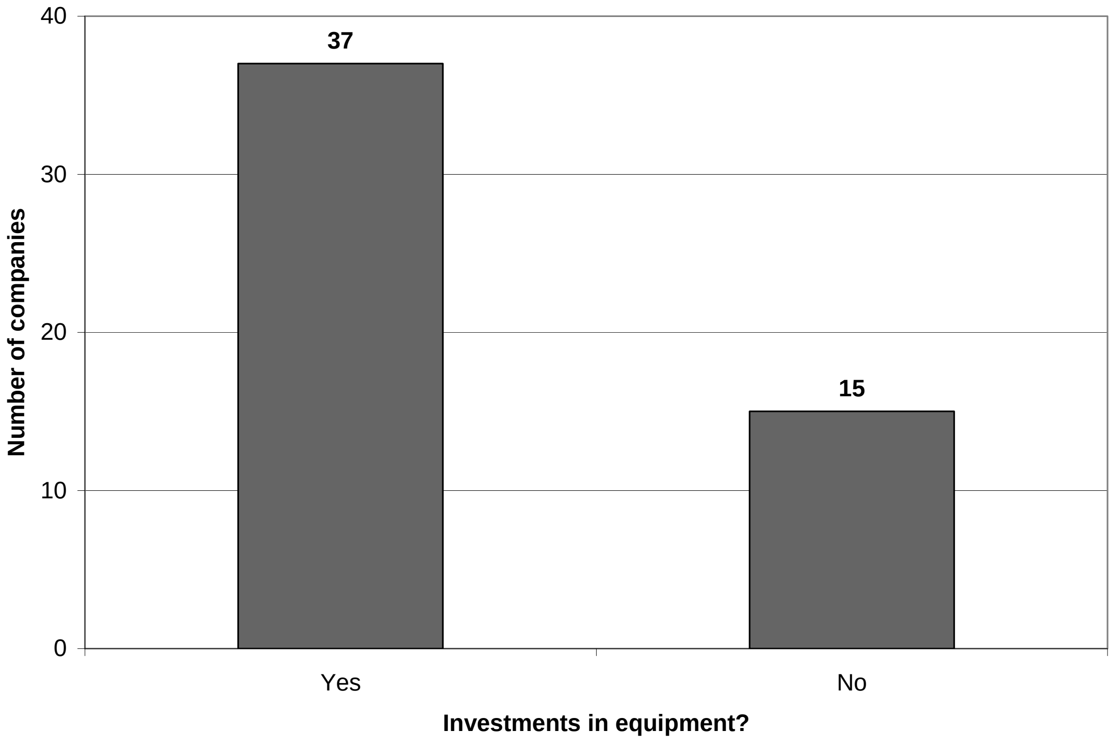


Figure 26 Companies that made C&IT investments in the last year

4.3 CONCLUSIONS

This chapter basically presents the results of the C&IT survey to determine companies' status establishing real-time data collection systems. Companies with both data and reporting capabilities have been highlighted as having the increased potential for productivity improvement. It was observed that line employees do not necessarily have access to the real-time data. The software and hardware infrastructures were studied. In hardware, the personal computers were closely followed by servers, while in software; Microsoft Windows and Microsoft SQL Server are the most used.

CHAPTER 5 - PRODUCTIVITY

5.1 INTRODUCTION

It is important for manufacturing companies to understand how competitive they are. As stated in the literature review; production is defined as a measure of economic efficiency which shows how effectively economic inputs are converted into output. Productivity is measured by comparing the amount of goods and services produced with the inputs that were used in production.

In this chapter we will discuss some responses related to productivity including the performance measures used and the ongoing activities pursuing productivity gains. Once the comparisons from the survey are made; multifactor productivity will be introduced as a possible metric for standardization.

5.2 PRODUCTIVITY METRICS

In the C&IT survey, companies where ask to identify the most important productivity metric used in their companies. The following options were given:

- Gross sales per employee
- Gross sales per direct labor employee
- Cost productivity
- Variance from financial standard
- Multifactor productivity
- Units per employee
- Proportional increase in product

The respondents where also allowed to add any other metric that was not part of our checklist. Figure 27 presents the results and includes a breakdown by sector.

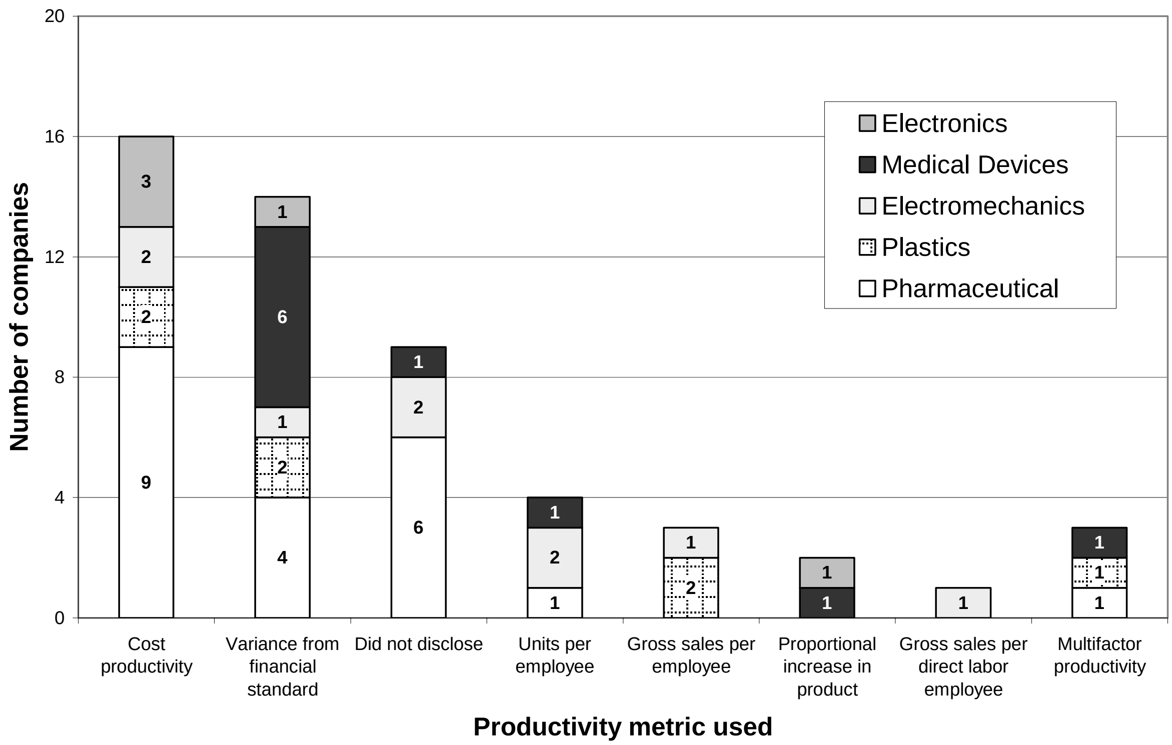


Figure 27 Productivity by sector

Looking at Figure 27 the most used metric for the companies in the survey is the cost productivity followed by variance from financial standard. At least seven (7) metrics are used. It is also notable that a large number of companies (9 out of 52) did not disclose the productivity metric. The results deserve some comments:

- Cost productivity is used by companies in all sectors except medical devices.
- Variance from financial standard is identified largely by the medical device sector
- The preference for specific metrics is not obvious.
- The variety of metrics in use does not help in making clear comparisons between sectors.

5.3 SATISFACTION WITH CURRENT PRODUCTIVITY PERFORMANCE

Respondents to the survey where asked about their satisfaction with current productivity performance. Figure 28 suggests that respondents that have a real-time data collection/reporting activity are highly satisfied (84 percent) while companies lacking the real-time setup expressed some degree of concern (52 percent unsatisfied with current productivity performance).

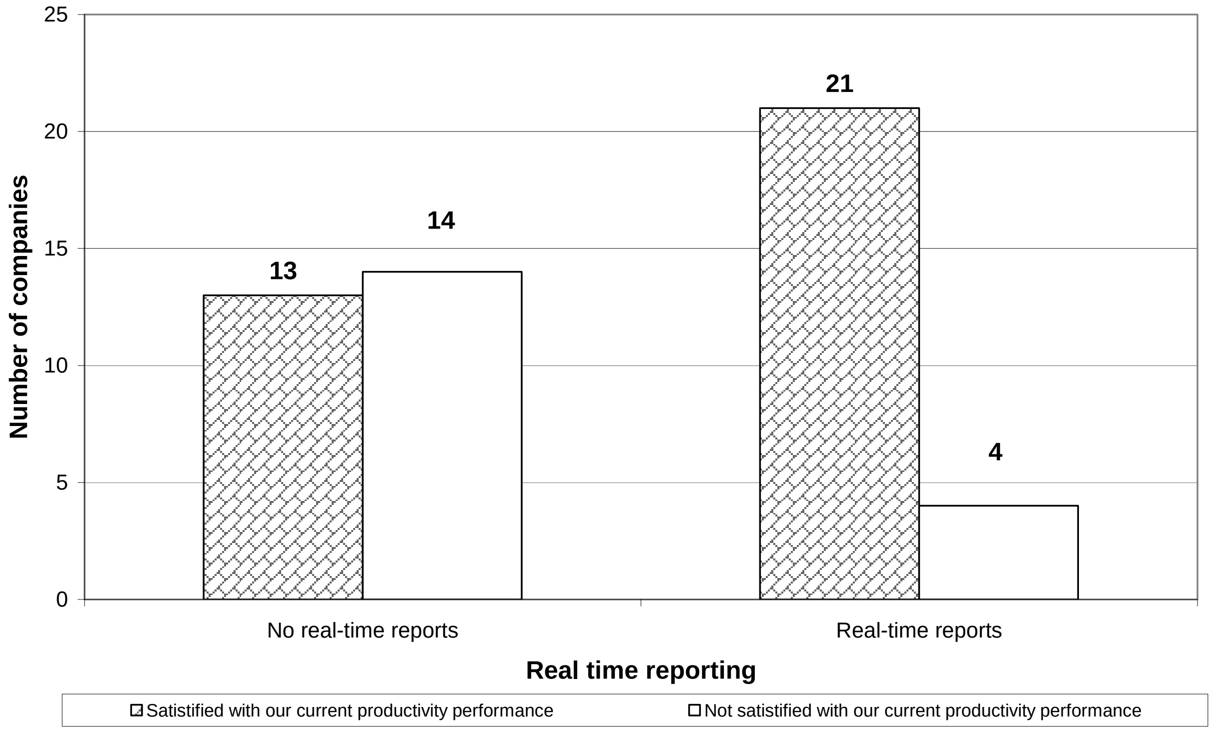


Figure 28 Satisfaction with current productivity performance – divided by real-time reporting

5.4 PRODUCTIVITY INITIVATIVES

The next Section focused on the company's desire for further productivity gains. Figure 29 shows and overwhelming interest in further gains (94 percent). Global competitiveness forces everyone to pursue improvement to maintain or improve the competitive position.

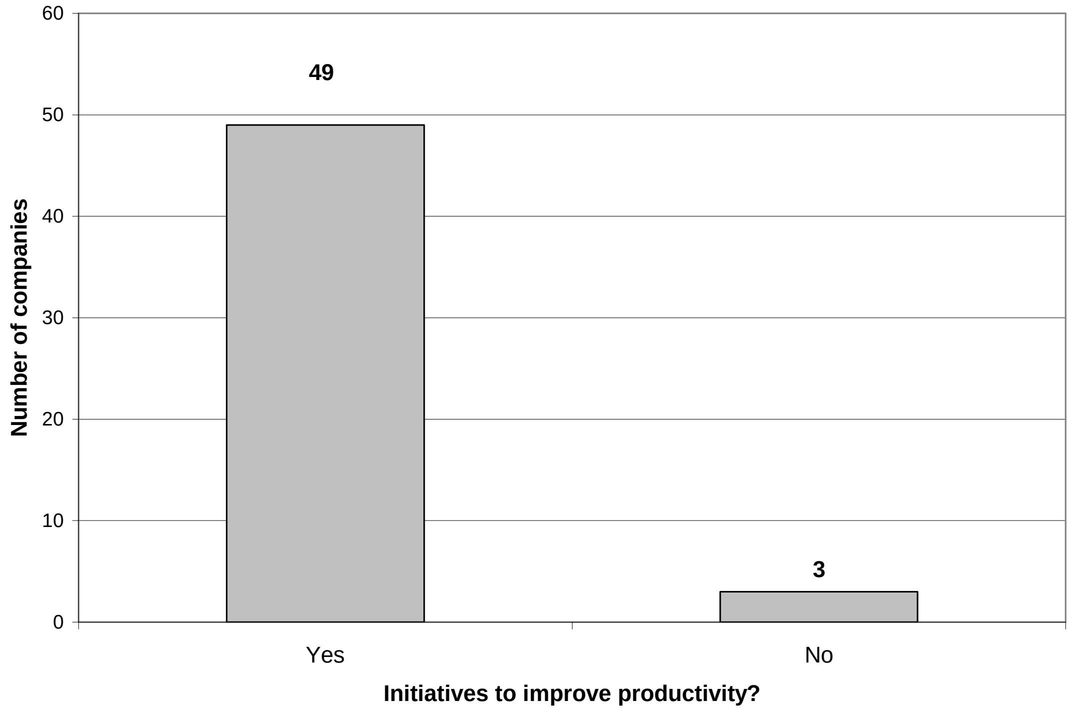


Figure 29 Working on initiatives to improve productivity?

5.5 PRODUCTIVITY COMPARISON WITH SISTER PLANTS

As previously stated; respondents to the survey where asked about the existence of sister plants of the companies sampled. Figure 25 and 26 described local companies compared with their sister plants in relation to C&IT implementation. Figure 30 presents how do local companies compare with sister plants with respect to productivity. Over 50% percent all companies in the sample (35 of 42) consider their plants better or at the same level as their sister plants in respect to productivity.

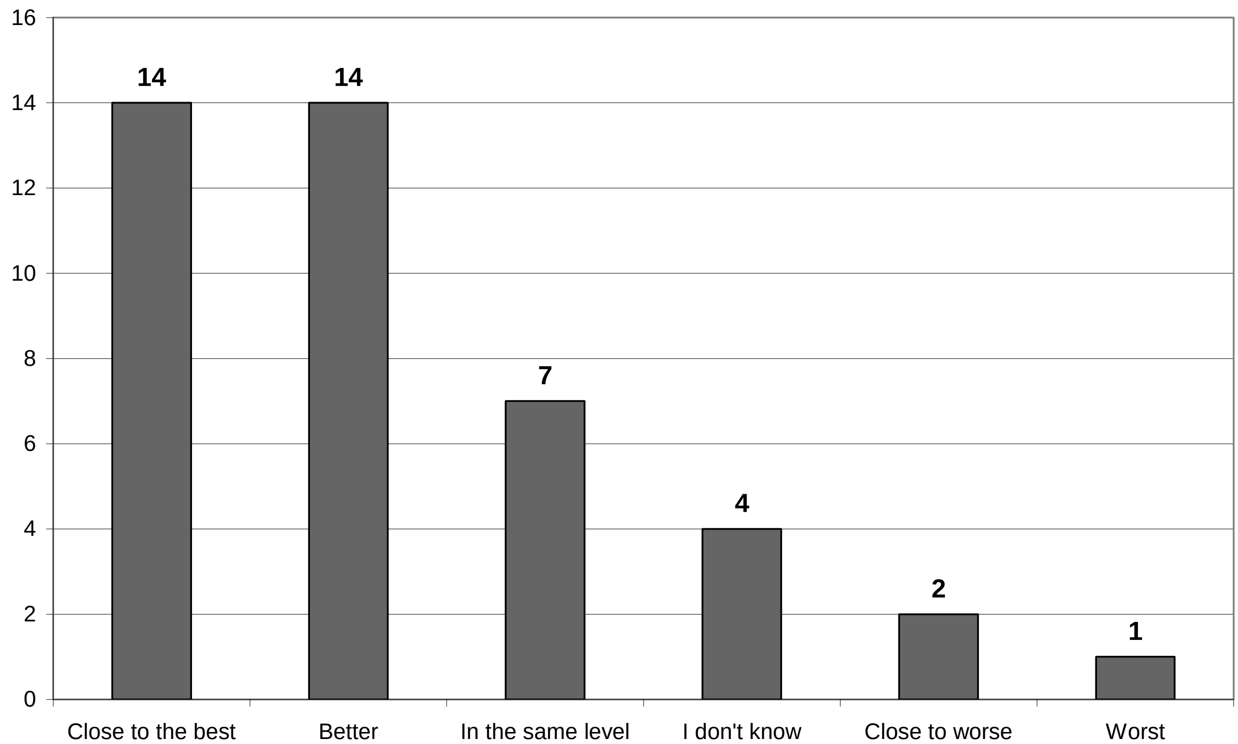


Figure 30 Comparison with sister plants - productivity

5.6 PRODUCTIVITY STANDARDIZATION

Section 5.2 showed that there are multiple productivity metrics in used. Comparisons can be facilitated if all participants converge to a single performance measure.

5.6.1 MULTIFACTOR PRODUCTIVITY

The suggested metric is based on KLEMS multifactor productivity as used by the Bureau of Labor Statistics. KLEMS stands for the factors used in the equation: Capital (K), labor (L), energy (E), materials (M), and purchased business services (S) inputs.

As described in Equation 5.1, productivity is the ratio of output obtained by input applied.

$$MP = \frac{output}{input} \tag{5.1}$$

The output can be measured by the value in dollars of the shipped units, while the inputs can be captured with the cost related to KLEMS: capital cost (K), labor cost (L), energy cost (E), materials cost (M), and purchased business services cost (S). The equation for our KLEMS multifactor productivity is then:

$$MP = \frac{DS}{K + L + E + M + S} \tag{5.2}$$

5.6.2 MULTIFACTOR PRODUCTIVITY – CASE STUDY

In order to do an initial evaluation of the proposed metric, a case study was developed. The numbers for the simulated manufacturing activity are presented in Figure 31.

Please complete the Input and Output areas; the Multifactor Productivity Value will be computed automatically	
Output	
$ shipped	18500
Inputs	
Capital $ (should consider depreciation and expenses)	1800
Labor $ (should consider the total people investment)	4905
Energy $ (includes all the billing that allows your plant to run as expected.)	100
Material $ (should consider raw materials, WIP levels and FGI)	2194
Purchased materials and services $	410
Result	
Multifactor productivity	**1.966**

Figure 31 Multifactor productivity case study

The following numbers where given by the user (numbers are masked to protect company's privacy):

- Outputs

  - Dollars Shipped (2003) - \$18,500K
- Inputs
  - Capital - \$1,800 K
  - Labor - \$4,905 K
  - Energy - \$100 K
  - Materials - \$2,194 K
  - Purchased materials and services - \$410 K

$$MP = \frac{DS}{K + L + E + M + S}$$

$$MP = \frac{18{,}500\mathrm{K}}{9{,}409\mathrm{K}}$$

With the previous information presented the value for multifactor productivity is: **1.97.** This result implies that each dollar of input is converted into 1.97 dollars of output.

5.7. REAL TIME DATA COLLECTION AND PRODUCTIVITY

One of the objectives of this research is to establish a causal relationship between real-time data collection and reporting capabilities and productivity data provided by the respondents. Data provided by the respondents is analyzed.

5.7.1 REAL TIME DATA COLLECTION AND PRODUCTIVITY CORRELATION

As one of the dimensions of the assessment; companies where asked to provide the value of their productivity metric for the years 2000 and 2002. Only 35 percent (18 of 52) of the respondents provided data.

It is important to recall that various productivity metrics were provided by the respondents. To compare results between respondents (irrespective of the metric used) the metric calculated the percent of change between 2000 and 2002; positive implied improvement while negative implied a decline. Figure 32 presents an example related to cost productivity. Given the 2000 and 2002 values, the resulting change is 33.3 percent.

Data entry	
Productivity year 2000	$ 1,500.00
Productivity year 2002	$ 2,000.00
Result	
Percent of change in productivity	33.33%

Figure 32 Percent change in productivity

Figure 33 presents the percentage change for the 18 responses received. The results are grouped by section and the x-axis shows if each company does ("Yes") or does not ("No") have real-time data collection/reporting capabilities. The graph shows that 17 percent (3 of 18) had a decline in productivity between 2000 and 2002. It is interesting to note that all three cases (circled) lack the real-time data collection reporting and tools.

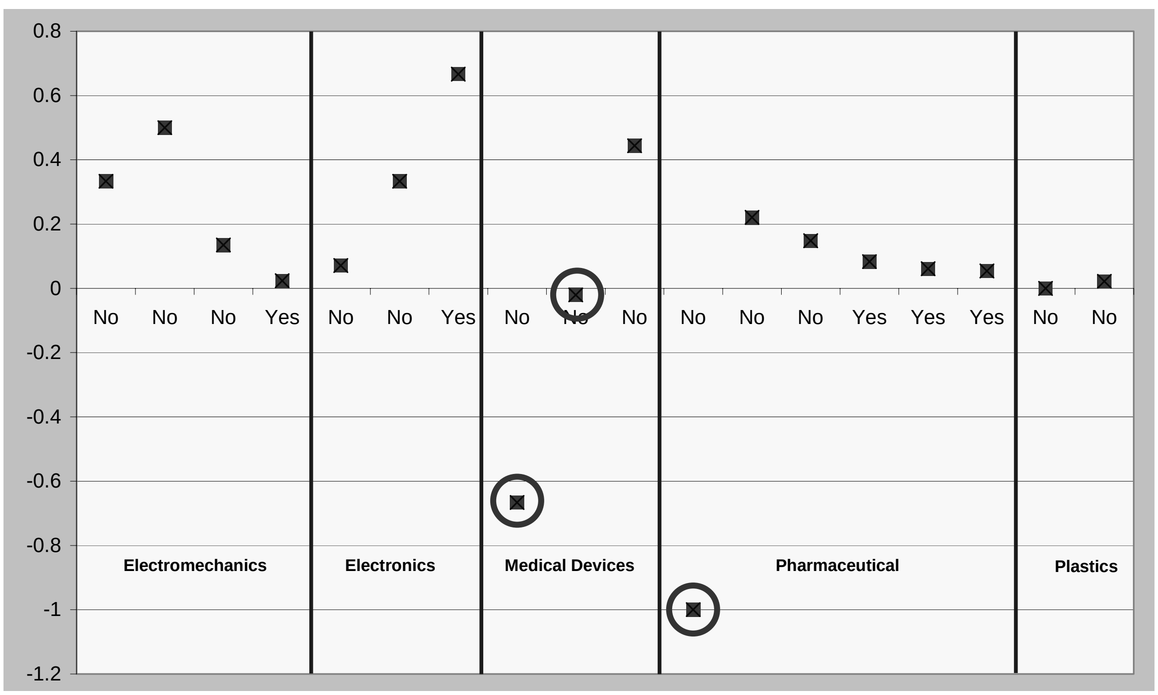


Figure 33 Productivity change by sector

5.7.1.1 STATISTICAL ANALYSIS

Two statistical tests were performed to the data in Figure 33.

- Determining if there is a difference in the percent change between "Yes" and "No" :
    - H0: $\Delta_{Yes} - \Delta_{No} = 0$
- Determining if percentage change varies between sectors:
    - H0: $\Delta_{pharma} = \Delta_{med\_dev} = \Delta_{electromech} = \Delta_{electron} = \Delta_{plastic}$

Differences between "Yes" and "No" to real-time data collection reporting capabilities was evaluated. The Kruskal Wallis (non-parametric) test was used to preclude the need for data distribution presumption. The analysis was performed in Minitab® and the test statistic had a P-value of P = 0.882; indicating that the null hypotheses can not be rejected.

Kruskal-Wallis Test for percentage change (2000 vs. 2002)

PercDif	N	Median	Ave Rank	Z
No	13	0.13522	9.4	-0.15
Yes	5	0.06122	9.8	0.15
Overall	18		9.5	

H = 0.02 DF = 1 P = 0.882
H = 0.02 DF = 1 P = 0.882 (adjusted for ties)

Figure 34 Kruskal Wallis Test for percentage change (Yes vs No)

The second test focuses on the possible differences in the percentage change between responses from different sectors. The Kruskal Wallis test was again used. Test statistic had a P-value of P = 0.234; indicating that the null hypotheses can not be rejected. Figure 35 summarizes these results.

Kruskal-Wallis Test: Percent of change - Sector

Sector	N	Median	Ave Rank	Z
Electromechanics	4	0.23428	12.1	1.12
Electronics	3	0.33333	13.8	1.54
Medical Devices	3	-0.02062	7.0	-0.89
Pharmaceutical	6	0.07228	8.5	-0.56
Plastics	2	0.01099	4.5	-1.40
Overall	18		9.5	

H = 5.57 DF = 4 P = 0.234
H = 5.57 DF = 4 P = 0.233 (adjusted for ties)

Figure 35 Kruskal Wallis Test: Percent of change - Sector

5.8 CONCLUSIONS

This chapter provided information on the variety of productivity measures used by Puerto Rico's manufacturing industries. With as many productivity metrics showed in the study it is desirable to suggest and implement a metric that will simplify comparisons within and beyond sectors.

One important tool that can help in this comparison is the multifactor productivity metric. It is important for the manufacturing industries to recognize the challenges with their current manufacturing industries and the importance of standardization.

In the effort of comparing real-time data collection and productivity it can be stated that at this moment there is no statistical evidence that those two factors are correlated.

The use of the questionnaire is an initial effort to measure C&IT activity in manufacturing. The intention is to become more acquainted with the plant's C&IT deployment, understanding the amount of investing and collaborating with the plants to assure that such investments have a significant impact in productivity and the bottom line.

CHAPTER 6 - CONCLUSIONS AND FUTURE WORK

6.1 CONCLUSIONS

This research wanted to present a statistically significant assessment to answer some key issues on Communication and Information Technology on Puerto Rico's plants. The questions of the survey covered both issues of real-time data collection and reporting and productivity metrics used in Puerto Rico's industries. With these questions it was desired to relate how real-time data collection and reporting benefited Puerto Rico's productivity.

The survey was implemented through the World Wide Web with a high response rate that covered five sectors: electronics, electromechanics, medical devices, pharmaceutical and plastics. The use of an online questionnaire allowed to respondents the freedom of answering the questionnaire at their own pace while allowing the researcher to receive responses immediately.

The questionnaire considered issues of reliability and validity. Validity was evaluated in the steps of pre-design of the questionnaire and will be evaluated once again in a future administration of the questionnaire, which should involve visits to the participating plants. Reliability was evaluated re-testing 18 companies with questions about the specific real-time data collection systems in the company. The ratio of reliability was calculated at 78%, which is above the 70% metric that determines questionnaires are reliable.

The study showed that less than 50% of the companies collect and report real-time data. This member confirms the existence of at least some data collection & reporting capabilities, but it does not determine the percentage of integration of C&IT in the companies. It is important to have a clear understanding on the shop-floor areas in which C&IT has been implemented to detect if specific areas have a bigger effect on productivity.

The sector that is less integrated with real-time data collection and reporting is the electromechanics sector, with only two out of the seven companies sampled responding positively. In the other sectors there is not a clear indicator that one sector is more advanced in C&IT than the others. Manufacturers in general should benefit from future government (PRIDCO) and academia (UPRM) efforts to motivate the integration of C&IT tools.

Companies collect data primarily for quality and product tracking; that means systems are used for monitoring defects and product movement through the shop-floor. This information matches with the key concerns expressed by companies in the areas of quality and product tracking.

Industries which have data collection/reporting activities are more motivated to continue the implementation of additional systems. It is very important to understand the company culture and disposition for those that do not collect real-time data. As we can see from Figure 14 most of the respondents to this question did not disclose the reasons.

For companies with partial or total integration of C&IT it is important to emphasize that this study found that line employees are not necessarily involved with the information provided by the C&IT system. The role of line operators in a company is critical; they are the first ones to detect process/quality problems. Thus, the use of C&IT systems by line employees could accelerate problem resolution, which might improve quality, downtime and thus productivity.

With the current data, the relation between real-time data collection/reporting and productivity could not be demonstrated. However, the interaction with manufacturing plants could be strengthened to improve the visibility to C&IT investment and deployment. The standardization of productivity measures will also help to facilitate data analysis.

KLEMS multifactor productivity was suggested as a universal measure. In using this metric, C&IT investment is part of capital investment (K). The use of this metric will also make it easier for government entities and interest groups to establish benchmarks.

Finally, an important message that should be communicated to all companies is the availability of cost-effective and reliable hardware and software solutions for successful C&IT implementation. An important task for interested companies is the hiring of internal (i.e., engineering and technicians) resources or the purchase of such services from service suppliers to install and maintain the needed solutions.

6.2 FUTURE WORK

In the next years the team from PRIDCO and UPRM will continue to evaluate companies C&IT efforts and to quantify the impact on company's productivity. Researchers from the academia should participate with industry in C&IT deployment and focus in significantly impacting the bottom line. C&IT implementation does not warranty improved performance since line and support personnel must learn how to take advantage of the new C&IT tools.

As the work in this project continues other assessment will follow including an improved questionnaire. The improved questionnaire should also be followed by plant visits in order to allow familiarization with the companies' real-time data collection coverage. Finally, as industries familiarize with the C&IT work by the PRIDCO/UPRM team, data should become more accessible through the web. The UPRM team should include resources from industrial engineering and electrical/computer engineering for enhanced coverage of C&IT, product flow, and productivity concerns.

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APPENDICES

Appendix 1 Letter from Manuel Hormaza

PRIDCO's Office of Science and Technology is leading an effort to design a roadmap to promote the development of a high technology Communications & Information Technology (C&IT) industry in Puerto Rico. A component of this effort is the identification of sectors with specific C&IT needs. Since local manufacturing represents over 40 percent of Puerto Rico's economy, we need to understand the status of C&IT implementation in our factories. This has motivated the creation of a "C&IT Enabled Manufacturing" initiative.

The goal of this initiative is to promote the use of C&IT on the factory shop floor to provide managers and employees with real-time feedback on their factory floor execution. In addition, C&IT will provide real-time intelligent execution instructions based on the combined status of the shop floor, the production schedule, and the supply chain needs. There is ample world wide evidence that such improvements should have a significant positive impact on productivity.

We have recruited Ms. Jannette Perez-Barbosa, graduate student at UPR Mayagüez Campus, who has selected the topic of "C&IT status in PR's manufacturing" as her Master's thesis. She is working with professors Mario Padrón and Pedro Resto as project advisors. It will be Jannette's responsibility to visit a significant sample of companies (over 50) to assist plant personnel in responding to a questionnaire focusing on C&IT. The questionnaire will be available on the Web so that responses are safely deposited into a database.

The questionnaire also requests productivity information for 2000 and 2002. In her research, Jannette wants to assess a possible connection between C&IT maturity at the plants and productivity results. We respectfully ask you to answer these questions as accurately as possible. Responses will be analyzed and presented as aggregates only, never linking the results with the source. Results will be delivered to each participating plant and will be shared with the manufacturing sector community at relevant professional forums.

The analysis of results, on C&IT maturity and productivity, should help us define the agenda for the near future. Please give Jannette all your support when she visits with you.

Truly Yours,
Ing. Manuel Hormaza
Director
PRIDCO's Office of Science and Technology

Appendix 2 Macro to generate uniform random numbers and sorting

```
Sub Macro1()
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
'C&IT Thesis topic
'Sample size selection macro
'Created by Jannette Pérez-Barbosa
'9/20/2003
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
'This macro was created to select the random sampling for each sector

'Nh  Strata
'72  pharma
'39  electromech
'35  Medical Devices
'23  plastics
'16  electronics
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
i = 0
pharma = 72
electromech = 39
med_dev = 35
plastics = 23
electronics = 16

Do While Cells(1 + i, 31) <> ""

        Select Case Cells(1 + i, 31)

                Case "chemical & pharma"

                        x = Roundup(Rnd * pharma)

                Case "electromechanical"

                        x = Roundup(Rnd * electromech)

                Case "electronics"

                        x = Roundup(Rnd * electronics)

                Case "medical devices"

                        x = Roundup(Rnd * med_dev)

                Case "plastic"

                        x = Roundup(Rnd * plastics)

        End Select

                Cells(1 + i, 32) = x

                i = i + 1
```

```
        Loop

End Sub

'http://www.ozgrid.com/forum/viewthread.php?tid=4579
Function Roundup(x As Double) As Double
If Int(x) >= x Then
Roundup = Int(x)
Else
Roundup = Int(x) + 1
End If
End Function
```

Appendix 3 Question writing checklist

Question-Writing Checklist

Stephen P. Borgatti

- [x] **Target the vocabulary and grammar to the population be surveyed.**
- [x] **Avoid ambiguity, confusion, and vagueness.**
- [x] **Avoid emotional language, prestige bias and leading questions**
- [x] **Avoid double-barrelled questions**
- [x] **Don't assume the respondent is an expert on themselves (unless you have no choice)**
- [x] **Avoid asking questions beyond a respondent's capabilities**
- [x] **Avoid false premises**
- [x] **Avoid negatives and especially double negatives**

Appendix 4 Communication and Information Technology Questionnaire

PRIDCO-UPRM COLLABORATIVE EFFORT TO ASSESS PR'S MANUFACTURING REALITIES WITH RESPECT TO AUTOMATED SHOP-FLOOR DATA COLLECTION AND REPORTING TOOLS

A. General Company Information

Company name: ____________________________
Contact person: ____________________________
Phone number: ____________________________
E-mail address: ____________________________
Local Company: ________ Foreign Company: ________

1. The plant belongs to the following manufacturing sector:
a) Pharmaceutical O
b) Medical Devices O
c) Electronics O
d) Electro-Mechanical O
e) Plastics O

2. Rank the top three concerns for your organization:
a) Cost competitiveness
b) Quality competitiveness
c) New product introduction
d) New equipment introduction
e) Research & development
f) Environmental Health and Safety
g) Other (specify) _______________

Ranking:
1. _____ 2._____ 3._____

B. C&IT Related Questions:

3. Are you collecting real-time data at the factory floor?
a) NO real-time data collection O
b) YES O

<u>If question #3 is YES</u>:

4. In what areas is data collected?
a) Planned versus actual production O

b) Product tracking through the shop floor O
c) Quality problems (defects, rejects) O
d) Equipment details (downtime, starvation, blockages) O
e) Maintenance/part replacement activity O
f) Other (specify) ______________________

If question #3 is NO:

5. In view of the fact that you are not collecting data, what is your major concern for not implementing?
a) Equipment acquisition cost O
b) System maintenance cost O
c) Lack of expertise within the plant O
d) Communication infrastructure acquisition cost O
e) Lack of support from Corporate office O
f) Regulatory and Validation concerns O
g) Other (specify) _______________________

6. How motivated is your business in implementing strategies for real time data collection:
a) Are interested in immediate implementation O
b) There are other currently other priorities, but will consider implementation in the near future. O
c) Its not in our priorities. O

If one or more were selected in question #4:

7. Are you generating real-time reports for your data?
a) Yes O
b) No O

8. If answer to question 7 is yes, which real-time reports are generated (check all that applies):
a) Planned versus actual production O
b) Product tracking through the shop floor O
c) Quality problems (defects, rejects...) O
d) Equipment malfunction O
e) Other (specify) ______________________

9. Identify which personnel uses the reports (check all that apply):
a) Line employees O
b) Supervisors O
c) Engineers O
d) Managers O
e) Plant manager O
f) Other (specify) ______________________

10. Communication infrastructures(s) used at factory floor level (select all which apply):
a) None O
b) Wired local area network O
c) Wireless local area network O
d) Wide area network O
e) Other (specify) ____________________

11. Please indicate, for each area of your factory floor, the communications infrastructure used (please circle Yes or No):

a) Electronics, electro-mechanical, plastics or medical devices sectors ---

Area	wired local area network	wireless local area network	wide area network	Other (specify)
Stockroom	Y / N	Y / N	Y / N	
Manufacturing	Y / N	Y / N	Y / N	
Testing	Y / N	Y / N	Y / N	
Utilities	Y / N	Y / N	Y / N	

b) Pharmaceutical sector ---

Area	wired local area network	wireless local area network	wide area network	Other (specify)
Stockroom	Y / N	Y / N	Y / N	
Bulk/ Continuous or Batch processes	Y / N	Y / N	Y / N	
Laboratory	Y / N	Y / N	Y / N	
Blending, Granulation, Drying, Tableting, etc	Y / N	Y / N	Y / N	
Other manufacturing systems	Y / N	Y / N	Y / N	
Filling / Packaging	Y / N	Y / N	Y / N	
Utilities	Y / N	Y / N	Y / N	

12. Identify platforms for data collection which apply:

a) Computers (PC's) O
b) Servers or workstations O
c) Programmable logic controllers O
d) Other (specify) _______________________

13. Identify the operating systems in use (check all that apply):
a) Windows (95, NT, 2000, XP) O
b) Unix O
c) Proprietary (specify) _____________________
d) Other (specify) __________________________

14. Identify which database systems are used to store real-time shop-floor data (check all that apply):
a) Microsoft SQL server O

b) Oracle O
c) Informix O
d) Proprietary (specify) ____________________
e) Other (specify) _________________________

15. Please complete for each area of the factory floor the information requested:

a) Electromechanical, Electronics, Plastics and Medical Devices sectors ---

Area	Computer (Hardware)	Operating System	Software Packages	Real Time Data Collecting?	Specific Data Collection Device(s)
Stockroom	Brand	Brand	Brand	Y / N	Brand
Manufacturing	Brand	Brand	Brand	Y / N	Brand
Testing	Brand	Brand	Brand	Y / N	Brand
Utilities	Brand	Brand	Brand	Y / N	Brand
Plant-wide ERP, MRP	Brand	Brand	Brand	Y / N	Brand
Corporate IT	Brand	Brand	Brand	Y / N	Brand

b) Pharmaceutical sector ---

Area	Computer (Hardware)	Operating System	Software Packages	Real Time Data Collecting?	Specific Data Collection Device(s)
Stockroom	Brand	Brand	Brand	Y / N	Brand
Bulk/ Continuous or Batch processes	Brand	Brand	Brand	Y / N	Brand
Laboratory	Brand	Brand	Brand	Y / N	Brand
Blending, Granulation, Drying, Tableting, etc	Brand	Brand	Brand	Y / N	Brand
Other manufacturing systems	Brand	Brand	Brand	Y / N	Brand
Filling / Packaging	Brand	Brand	Brand	Y / N	Brand
Utilities	Brand	Brand	Brand	Y / N	Brand
Plant-wide ERP, MRP	Brand	Brand	Brand	Y / N	Brand
Corporate IT	Brand	Brand	Brand	Y / N	Brand

C. Productivity Related Question:

16. Which productivity measure does your company prefer?
    a) Gross sales per employee O
    b) Gross sales per direct labor employee O
    c) Cost productivity O
    d) Variance from financial standard O
    e) Multifactor productivity O
    f) Units per employee O
    g) Proportional increase in product O
    (Combination of inputs used in the production of that output, such as labor, capital, utilities and materials)
    h) Other (please specify) ______________________________________

2000 2002

17. For the metric selected above, please provide historical results: _____ _____

D. C&IT investment Related Question:

18. Have investments been made in C&IT for the shop floor in the last fiscal year (2002):
a) Yes
b) No

19. If you answered yes to question 18, the funds were used for the following (mark all that apply):
a) Software O
b) Data Collection Devices (scanners, barcode readers,…) O
c) Communication infrastructures (servers, routers, switches,…) O
d) Other ____

20. Please give an estimate of the percent of the total 2002 budget assigned to C&IT:
____

E. Comparison with Sister Plants

21. Your company has sister plants in (mark all that apply):
a) Puerto Rico O
b) Caribbean O
c) USA O
d) Asia O
e) Europe O
f) Has no sister plants O

22. Are you satisfied with your current productivity performance?
a) Yes, we are satisfied with our current productivity performance O
b) No, we are not satisfied with our current productivity performance O

23. Are you working on plant-wide initiatives geared at significant productivity improvement?
c) Yes, we are currently working on such initiatives O
d) No, productivity is not a key issue for us right now O

24. If you have sister plants, how does your site compare with respect to C&IT implementation?
a) Better O
b) Close to the best O
c) In the same level O

d) Close to worse O
e) Worst O
f) I don't know O

25. If you have sister plants, how does your site compare with respect to productivity?
a) Better O
b) Close to the best O
c) In the same level O
d) Close to worst O
e) Worst O
f) I don't know O

F. C&IT Contact Information

26. Please identify three key suppliers in your automated shop-floor data collection and reporting efforts (company name, key contact person, phone and e-mail); these could be invited to a Communications & Information Technology Forum being planned for the near future at UPR Mayagüez Campus.

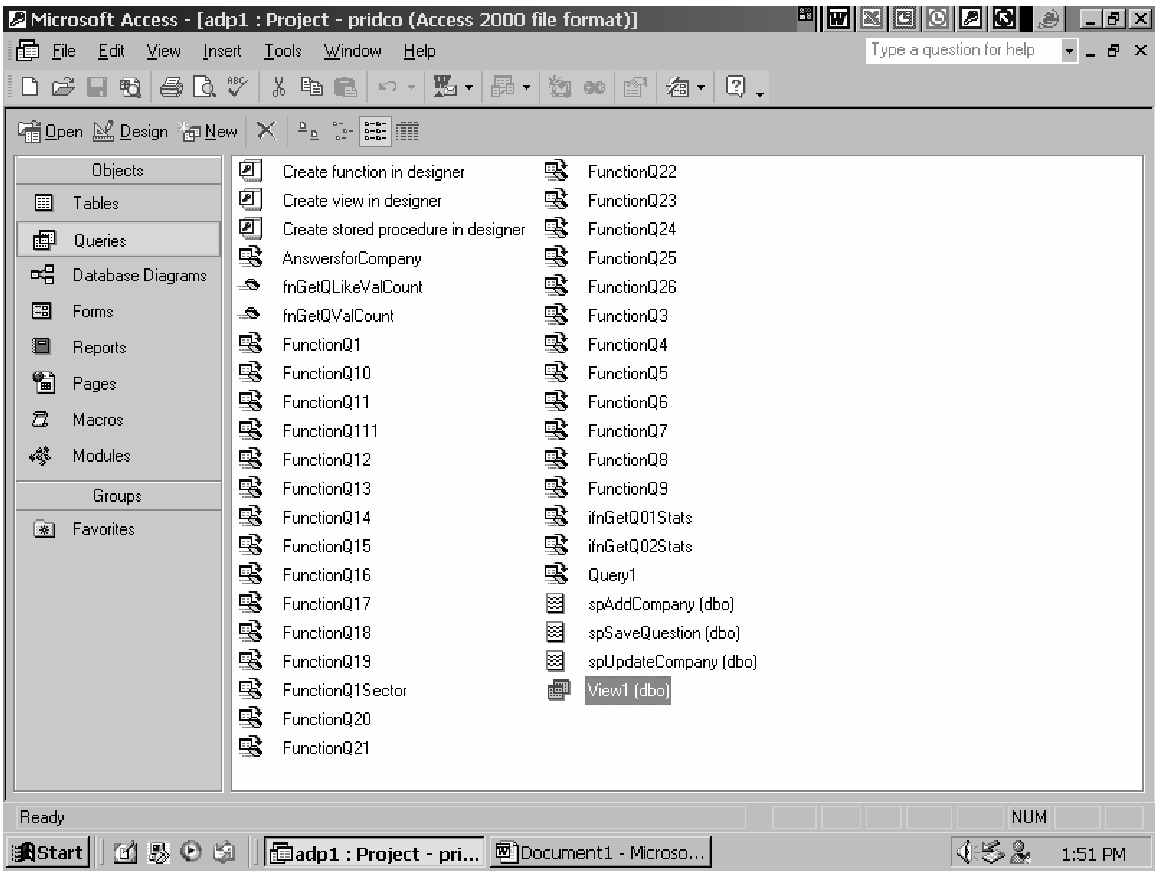
Company #	Company Name	Key Contact	Phone	Email
1				
2				
3				
4				

Appendix 5 Calculation of Cronbach's alpha

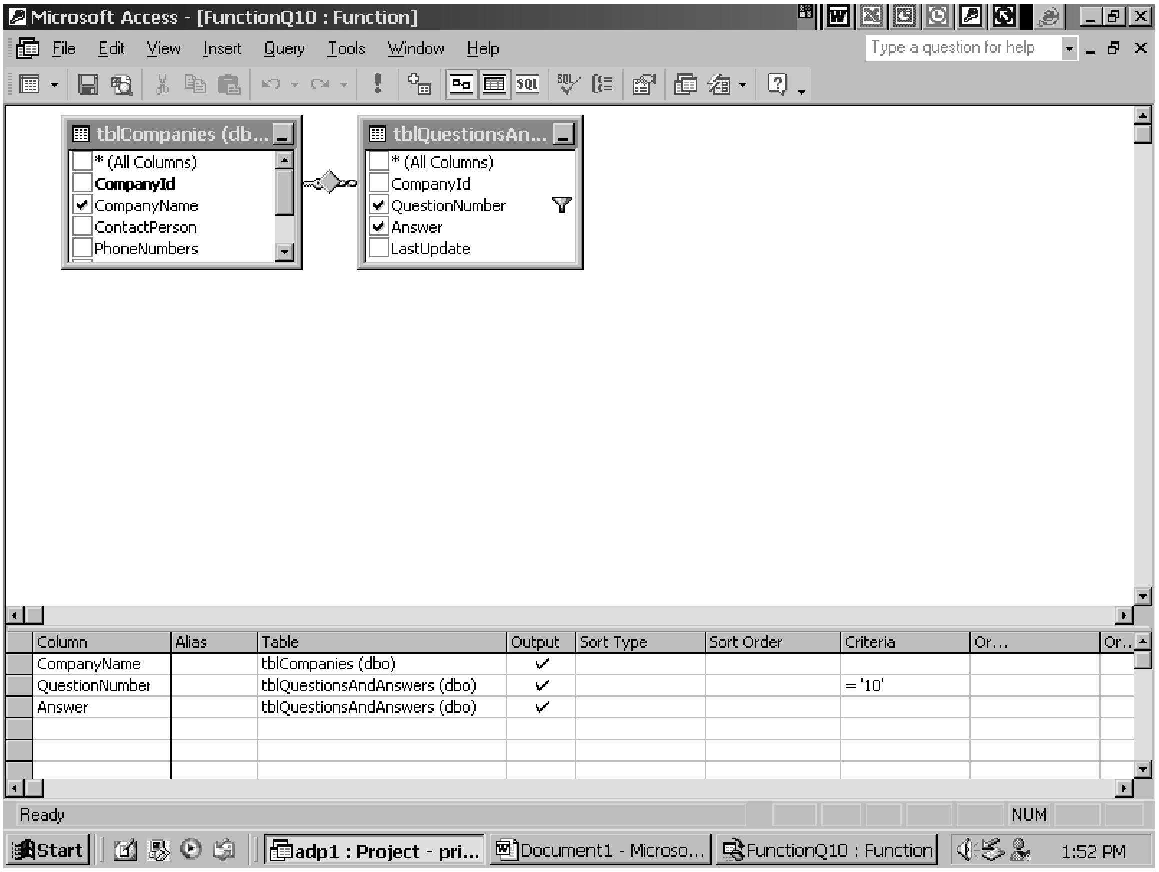
Question	**2**	
Responses	**18**	
		MS
SS tot	**230.5555556**	
SSq3	**168.0555556**	**9.88562**
Ssrev	**25**	
Ssresidual	**37.5**	**2.20588**
s sq people		**3.83987**
s2(people) = [MS(people) – MS(residual)] / k = (4.8846 – 0.6795) / 2 = 2.1026		
The Alpha coefficient is calculated as: (k2 * s2 (people)) / (k2 * s2 (people) + k * s2 (residual))	**77.69%**	

Appendix 6 MS Access tools used in the design

1. Function used for Queries in access



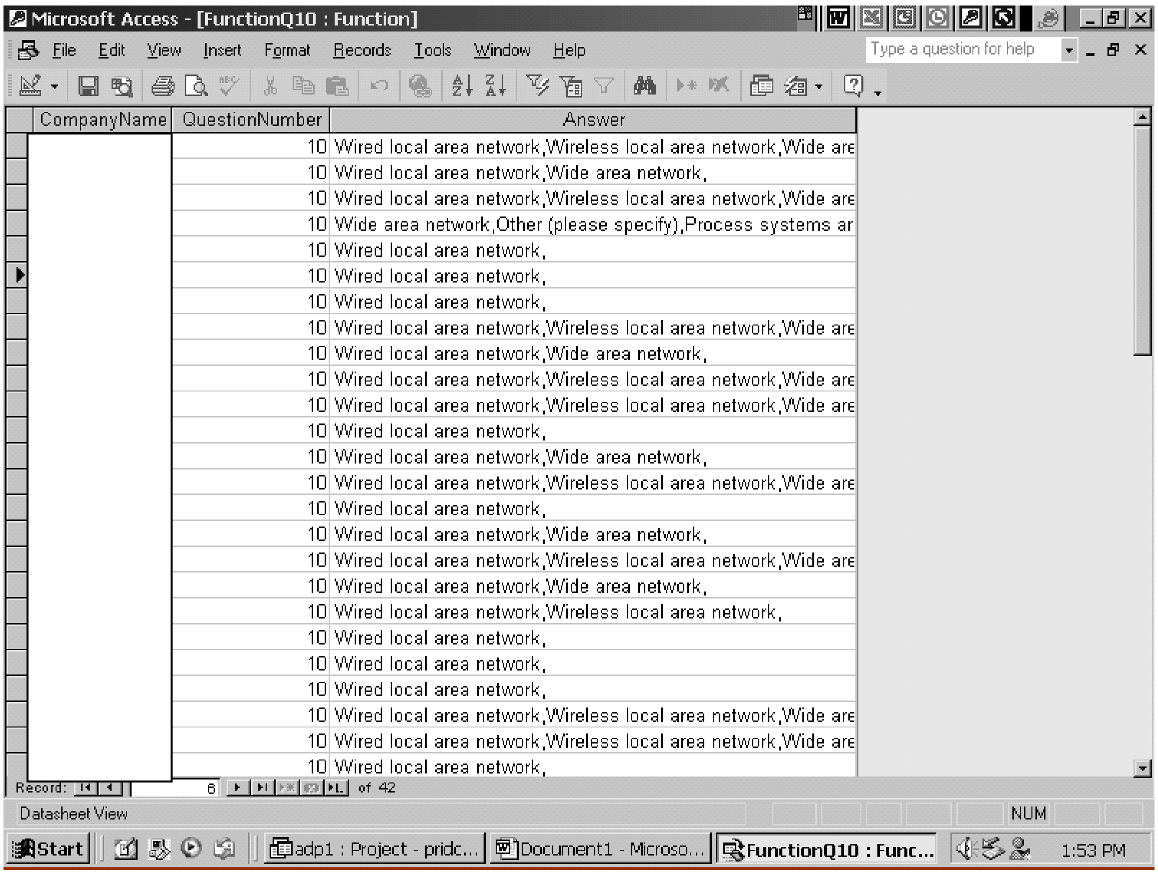
2. Construction of a function in MS Access



3. SQL Code for a a function

```
ALTER FUNCTION PridcoUser.FunctionQ10
()
RETURNS TABLE
AS
RETURN ( SELECT     dbo.tblCompanies.CompanyName,
dbo.tblQuestionsAndAnswers.QuestionNumber, dbo.tblQuestionsAndAnswers.Answer
FROM        dbo.tblCompanies INNER JOIN
                 dbo.tblQuestionsAndAnswers ON dbo.tblCompanies.CompanyId =
dbo.tblQuestionsAndAnswers.CompanyId
WHERE     (dbo.tblQuestionsAndAnswers.QuestionNumber = '10') )
```

4. Records as seen in the database (company names are protected)



Appendix 7 HTML and ASP code

1. Q1 - HTML and ASP

```
<%@ Page Language="vb" AutoEventWireup="false" Codebehind="Q1.aspx.vb"
Inherits="pridco.WebForm1"%>
<!DOCTYPE HTML PUBLIC "-//W3C//DTD HTML 4.0 Transitional//EN">
<HTML xmlns:v="urn:schemas-microsoft-com:vml">
	<HEAD>
		<title>Question1</title>
		<meta content="Microsoft Visual Studio.NET 7.0"
name="GENERATOR">
		<meta content="Visual Basic 7.0" name="CODE_LANGUAGE">
		<meta content="JavaScript" name="vs_defaultClientScript">
		<meta
content="http://schemas.microsoft.com/intellisense/ie5"
name="vs_targetSchema">
	</HEAD>
	<body bgColor="#d3ffbd" MS_POSITIONING="GridLayout">
		<form id="Form1" method="post" runat="server">
			<asp:label id="Label1" style="Z-INDEX: 101; LEFT:
24px; POSITION: absolute; TOP: 90px" runat="server" ForeColor="#004000"
Font-Size="Large" Font-Bold="True" Height="30px" Width="594px">The
plant belongs to the following manufacturing sector :</asp:label><IMG
style="Z-INDEX: 103; LEFT: 223px; WIDTH: 396px; POSITION: absolute;
TOP: 19px; HEIGHT: 45px" height="45" alt="logo rum"
src="http://ccc.uprm.edu/publications/colegio.jpg" width="396"><A
href="index.asp"></A><IMG style="Z-INDEX: 102; LEFT: 26px; POSITION:
absolute; TOP: 19px" alt="logo pridco"
src="http://www.prhta.org/Others/Images/logo_pridco.gif">
```

```
                  <asp:radiobuttonlist id="radio1" style="Z-INDEX: 104;
LEFT: 24px; POSITION: absolute; TOP: 128px" runat="server"
ForeColor="DarkGreen" Font-Size="Medium" Height="73px" Width="249px">
                        <asp:ListItem
Value="Pharmaceutical">Pharmaceutical</asp:ListItem>
                        <asp:ListItem Value="Medical Devices">Medical
Devices</asp:ListItem>
                        <asp:ListItem
Value="Electronics">Electronics</asp:ListItem>
                        <asp:ListItem
Value="Electromechanics">Electromechanics</asp:ListItem>
                        <asp:ListItem
Value="Plastics">Plastics</asp:ListItem>
                  </asp:radiobuttonlist><asp:button id="Button1"
style="Z-INDEX: 105; LEFT: 113px; POSITION: absolute; TOP: 286px"
runat="server" Height="27px" Width="117px" Text="Next
>>"></asp:button></form>
      </body>
</HTML>
```

Parte de VB

```
Imports System.Data.SqlClient
Public Class WebForm1
    Inherits PWA
    Protected WithEvents Button1 As System.Web.UI.WebControls.Button
    Protected WithEvents Label1 As System.Web.UI.WebControls.Label
    Protected WithEvents radio1 As
System.Web.UI.WebControls.RadioButtonList
    Dim QuestionNumber As Integer = 1

#Region " Web Form Designer Generated Code "

    'This call is required by the Web Form Designer.
    <System.Diagnostics.DebuggerStepThrough()> Private Sub
InitializeComponent()

    End Sub

    Private Sub Page_Init(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles MyBase.Init
        'CODEGEN: This method call is required by the Web Form Designer
        'Do not modify it using the code editor.
        InitializeComponent()
    End Sub

#End Region

    Private Sub Page_Load(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles MyBase.Load
        DoCheck()
    End Sub

    Private Sub Button1_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button1.Click
```

```
        Answer = Request.Form("radio1")

        'if the uyser is loged in
        If UserID <> 0 Then
            Response.Write("<br><br><br><br><br><br><br><br>error=" &
oTM.Save(UserID, QuestionNumber, answer))
        Else
            Response.Write("You need to login again.")
        End If
        If answer = String.Empty Then
            Response.Redirect("Q1.aspx")
        End If

        Response.Redirect("Q2.aspx")
    End Sub

End Class
```

Appendix 8 Symbols

A - multifactor productivity

Q - output

K - capital input

L - labor input

IP - intermediate purchases input

t - current time period

N - items in population

n - items in the sample

N_h - total number of units in stratum

S_h - variance in each population stratum

n_h - total number of units in stratified sample

y_{ih} - value for the i_{th} unit in the h_{th} stratum

W_h - stratum weight in population $W_h = \frac{N_h}{N}$

w_h - stratum weight in sample

f_h - sampling fraction in the stratum $f_h = \frac{n_h}{N_h}$

w_k, w_l, w_{ip} - cost share weights

p_h - fraction in the stratum that answered "Yes" to question #3

a_h - number of companies in the stratum that answered "Yes" to question #3

q_h - fraction in the stratum that did not answered "Yes" to question #3

$q_h = (1 - p_h)$

k - number of items in the group

s^2_{res} - variance of residual components

s^2_p - variance component for person.