LEVEL ONE INDUSTRIAL AUTOMATION: CHOOSING NETWORK CONTROL SYSTEMS

By

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A thesis submitted to the Faculty of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of
Master of Applied Science in Technology Innovation Management

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Ottawa, Canada, K1S 5B6

December 2009

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Ottawa ON K1A 0N4
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Your file *Votre référence*
ISBN: 978-0-494-63465-3
Our file *Notre référence*
ISBN: 978-0-494-63465-3

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in partial fulfillment of the requirements for the degree of
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ABSTRACT

Data mining techniques and public information available on industrial automation (IA) company websites were used to classify the product or service offers of 214 IA companies and Network Control Systems. Based on the market offer description, the results suggest that the clustering of IA companies can be grouped this way: (i) concentrates on specific features (key words) in choosing the NCS; (ii) two NCSs (protocols) as the choice for level one in IA depending on usage (Ethernet or ModBus); (iii) one suggested NCS (LAN) as the choice for level one in IA for all their offers; and (iv) a choice between three NCSs (ModBus, Ethernet, or LAN) as the choice for level one in IA. The results indicate that the applications in industrial automation can be divided into three types: general applications, secured applications and non secured applications. A selection guide is presented based on specific keywords.

ACKNOWLEDGEMENTS

My research work has been supervised by Prof. Douglas King; during the work he has continually provided me with his inspiration, encouragement, and support, Thank you! Several other professors have also enriched my education and research experiences at Carleton .I would like to thank Professor Antonio Bailetti, Professor Michael Weiss, and Professor Steven Muegge; they have continually provided me with many useful guidelines and constructive comments for my research work.

Finally, but most importantly, this dissertation is dedicated to my family for their endless love and support, especially to the soul of my father, who used to encouraged me to continue to learn.

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1. INTRODUCTION

The Level one network control system (NCS), or fieldbus, is a key and important component for building automation systems. Therefore, in order to fulfill the real-time requirements of field devices – like sensors, actuators, and controllers – a wide variety of standards organizations, suppliers, and integrators have developed assorted fieldbus protocols. As a result, many standards were only recently announced as international standards. The application of the Level one network control systems has been restricted due to the high cost and the inconvenience in interfacing with multivendor products. In order to overcome these problems, it is important to choose the NCS most suitable for the end users, according to the application. (RoBler F. and Geppert B., 1997)

Level one network control system (NCS) technology in industrial automation (IA) is comparatively complicated because of the number of solutions available and also due to the assortment of applications. This assortment of applications is responsible for the large number of solutions available. The analysis of the basic requirements is comparatively standard, as they will always affect linking sensors, actuators, and field controllers together; however, the options in architecture are wide and can enforce the call for definite performances. The required services themselves and the Quality of Service (QoS) expected are essentially determined by the particular applications. (Parrott J. T., Moyne J. R., and Tilbury D. M. 2006)

For more than 20 years now, the phrase “level one NCS” has been very widely used. Its general meaning is a network for linking field devices such as sensors and actuators; field controllers such as PLCs, regulators, drive controllers, etc.; and man-machine interfaces. But this is only an informal definition and calls for more in-depth analysis. Level one NCS technology stands for a broad area of problems which are similar, but not exactly identical, in nature. Level one NCS technology includes a wide range of solutions and techniques which, seen as closely related, are different from each other. The IA companies recognized the strategic importance of the level one NCS in IA. This research seeks to find the roots and present status of the level one NCS technology, including management and scientific analysis, and standardization in choosing the NCS protocol. (Lian F.L., Moyne J. R., and Tilbury D. M., 2005)

The modification of communication architecture from point-to-point to common bus, however, presents different forms of time delay uncertainties between sensors, actuators, and controllers. These time delays come from the time sharing of the communication medium as well as the extra time needed for physical signal coding and communication processing. The characteristics of time delays may be constant, bounded, or even random, depending on the network protocols chosen and the hardware chosen. This type of time delay could affect a system's performance and possibly cause system instability. The next figure (figure 1) presents the Layout Architecture in Industrial Automation. (Lian F. L., et al, 2002)

Figure 1. Industrial Automation Layout Architecture

1.1. Objective

Research question

What are the criteria and market differentiation in choosing the NCS for level one IA?

The objective of this research is to use the public data on websites of IA manufacturers, suppliers, and integrators in order to identify the criteria and market differentiation for the choice of NCS.

1.2. Deliverables

The outcomes of this research are:

- Database of IA suppliers, manufacturers, and integrators (and their offers); Key factors that will help the customers and users to select the choice of NCS for level one industrial automation;
- Framework for classifying NCS for level one industrial automation -> tool for selection; Documentation of issues encountered and how they were resolved (especially data gathering);
- Identify key words that can be combined into factors that lead to criteria for the choice of NCS, which result in improved quality of NCS as used in real time applications. And Group IA falls into clusters based on the classification criteria.

1.3. Contributions

This research makes the following contributions:

- Analysis of factor analysis outputs to provide a usable framework for NCS classification and selection
- A convenient, comprehensive listing of IA suppliers, manufacturers, and integrators using public data to identify related offers
- A defined process for using publicly available information to categorize information technology offers according to criteria for selection by integrators and end users. This process can be reused by future researchers.

1.4. Relevance

This research is relevant to automation industry manufacturers, suppliers, and integrators (top management) offering the NCS. It may lead to improved reliability and efficiency of the controllers, will help to reduce costs; it will also help to motivate those manufactures, suppliers

and integrators to increase the performance and flexibility of their NCS offers, the end-to-end business solution, user satisfaction, and care about reliability and quality of communication. It is also relevant to industrial plants (technical management) where it will indirectly help to increase the performance and flexibility of NCS, to increase reliability and reduce maintenance costs in order to increase productivity, to select the most suitable NCS for safety guarantees, and to design an optimum network infrastructure.

This research is relevant to academia as well. It will provide topics for future research, and presents a validated process using factor analysis; documenting the issues encountered, and how these issues were resolved.

Last and not least it is relevant to control managers and telecom engineers because they can use the selection guide and their application-specific factors to evaluate and select the most suitable NCS, and to increase reliability and reduce maintenance cost.

1.5. Organization

This thesis has been organized into six chapters. The first chapter contains an introduction, objectives, deliverables, contribution of the thesis, and to whom it is relevant. The second chapter includes a review of the current literature referring to IA companies' websites and network control systems. In the third chapter, the thesis scheme and method are presented in detail. The fourth chapter details the data collection results and analysis, and chapter five discusses the results. Chapter six, the last chapter, includes conclusions, limitations of the study, and future research opportunities.

2. LITERATURE REVIEW

This chapter, which assesses the literature, is arranged into five sections. Section 2.1 reviews the literature on the technology management problems related to NCS. Section 2.2 reviews the literature on user perception. Section 2.3 reviews the benefits and values. Section 2.4 reviews the NCS evaluation. Finally, Section 2.5 provides lessons learned.

2.1. The Technology Management Problems

Control systems with networked communication, known as NCSs, have various advantages over point-to-point wired systems. NCSs have improved reliability through a reduced volume in wiring, easier systems integration, simpler troubleshooting and maintenance, and the possibility for distributed processing. There are two types of communication networks. Data networks are qualified by big data packets, comparatively infrequent bursty communication, and high data rates; they generally do not have hard real-time constraints.

Control networks, in contrast, must carry countless small but frequent packets among a relatively large set of nodes to meet the time-critical requirements.

The key factor that differentiates control networks from data networks is the capability to support real-time or time-critical applications. The modification of the NCS architecture from point-to-point to common bus, still presents different forms of time delay uncertainties between sensors, actuators, and controllers. These time delays result from the time sharing of the communication medium as well as the additional time needed for physical signal coding and communication processing. The characteristics of time delays may be steady, bounded, or even random, based on the network protocols used and the chosen hardware. This type of time delay could possibly reduce a system's performance and may cause system instability. (Lian F.L., et.al , 2005)

EtherNet, ControlNet, DeviceNet

The Ethernet continues to gain momentum as an NCS in the industrial automation market; it is changing the way control engineers use their NCSs. In the past, NCSs were regarded as one-dimensional – they executed one task and did it very well – transferring process data between networked devices in a quick and deterministic way. Commonly these devices were on a local section, insulated from higher-level networks. Today, industrial Ethernet systems execute this basic task and much more. Users are no longer under pressure to buy proprietary NCS elements from a small number of marketers.

Ethernet networks are gaining greater usage in the manufacturing automation and process control – and for good reasons: they save money and they simplify operations. There are many advantages in applying Ethernet NCS in manufacturing. Not only are they faster than most proprietary systems, but they are also clearly cheaper. Selecting the suitable NCS will provide the basics necessary for a plant’s asset management capabilities. The next table (table 1) shows the comparison between the three main choices in NCSs.

Table 1. Parameters of NCSs.

Parameter	DeviceNet	ControlNet	Ethernet
Max. number of nodes	64	99	>1000
Max. data size (byte)	8	504	1500
Min. message size (byte)	47/8	7	72
Max. length (m)	100	1000	2500
Data rate (Mbps)	0.5	5	10
Bit time (μ s)	2	0.2	0.1
Typical Tx speed (m/s)	coaxial cable: 2×10^8		

ControlNet is a deterministic NCS that supplies the highest quality throughput and efficiency at maximum network loads. Scheduled and unscheduled segments in each NCS cycle make ControlNet suitable for both time-critical and non-time-critical messages.

DeviceNet is a serial NCS; it was developed mainly for applications in the automotive industry, but it is also able to offer good performance in other real time industrial applications. DeviceNet is a comparatively low cost NCS that connects devices to a network. The major disadvantage of DeviceNet compared to other NCSs is the slow data rate (a maximum of 500 Kb/s). Therefore the throughput is limited.

Competitive Edge and User Satisfaction

Industrial automation hopes to use the NCS and a recent generation of control architecture in response to high flexibility and productivity. Methods and design steps related to the new generation of control architecture can be defined in terms of decentralization of control tasks through multiple processing. NCS technology solutions – such as EtherNet, ControlNet and

DeviceNet – provide greater flexibility for those choosing NCS systems for their application. End users can now select any protocol that could suit their application from a pool of available NCSs.

Meeting Efficiency Requirements

For NCSs end users, knowledge is the basis of the successful management of level one NCS. Customers have to be aware that some protocols have limited benefits, and others are not the best choice for a specific application, which makes choosing the NCS challenging. So they have to examine and analyse their equipment and know their applications before moving forward. The supplier, integrator, and manufacturer community have developed a solution to treat common concerns about NCSs in the field, especially those associated with bus power and communications security; their solution is in offering all available protocols (standard) to allow the customer to chose what he believes could best suit his application.

2.2. User Perception

Today many customers or end users face the critical task in choosing the NCSs for their process control system at level one. Their selection can affect the cost and performance, so it is important to understand the differences between different available NCSs before making a major investment.

Choosing the right NCS, whether customers are trying to start up a plant faster or streamline maintenance tasks, will give the ability to provide level one plant floor information from intelligent devices over the plant network into an asset management application.

Applications Used

Some of the IA applications are robotics, production line, packaging plant, and mobile robotics such as assembly automation, supervisory control and data acquisition, SCADA applications, etc. NCSs have been in use not only in the IA and control areas but also in many applications such as instrumentation, aerospace, automobiles, home/office automation (intelligent building), process control, navigation, consumer products, etc.

End users with the traditional distributed control system (DCS) type applications found in the chemical industries, petrochemical, oil and gas, and refining should take care in selecting the standard NCS when planning for the future.

Evaluating a Network Protocol

The end users or consumers don't know what to choose from the different NCSs available. It is hard to tell which one will best suit their needs and applications, and so many large companies have decided to release their own NCSs that work on different standards and architecture. It is worth mentioning that currently there are more than 30 different NCS standards available in the technology marketplace, and some of them are national standards. So control or telecommunication engineers have to take care in evaluating their existing assets in order to decide the NCS to use for their applications.

Requirements and Network Performance Analysis

Recently there have been a large number of NCS protocols available for applications at level one in IA. The goal of NCS is to provide a guaranteed QoS, such as deterministic time delays and maximum throughput for real-time control applications. These NCSs target various types of IA and processing applications and are distinguished through static parameters such as data rate, message size, medium length, supported topology, number of nodes. They also have dynamic parameters such as medium access control mechanism, message connection type, interoperability, and interchangeability.

In NCSs, the performance of the control system is presumed to be affected by network-induced parameters such as packet losses, jitters, delays, and link failures.

Managing NCSs is fundamental to effective and efficient system operations. It will save time and money through scheduling maintenance appropriately and more effectively using the assets that are available.

2.3. Benefits and Values

As an outcome of extended research and development, various NCSs for industrial automation has been released. For example, Controller Area Network (CAN) was originally developed in 1983 by the German company Robert Bosch for use in car industries, and it is also being used now in many other IA applications. Another example of industrial networks is Profibus developed by six German companies and five German institutes in 1987. Profibus is a broadcast bus protocol that operates as a MultiMate/slave system. Many other NCSs, including Foundation Fieldbus and Device-Net, were also developed about the same time period. Most of

these protocols are typically dependable and strong for real-time control purposes. (Tipsuwan and Chow, 2003).

Improving Throughput

Throughput is defined as the amount of information that is carried by a network at a given time. Peak and sustained throughputs refer to the capability of the network under different conditions. The NCS - QoS includes improving throughput; predicting time delays, utilization, and efficiency; minimizing the lost data rate; and calculating message schedulability. Comparisons of NCS - QoS metrics, such as network utilization and efficiency, with static network parameters, such as message size and data rate, were considered for various popular control networks. The consequences rendered a first understanding of the NCS time delay without regarding other network dynamic parameters that may cause time delay variance.

Network Quality of Service (QoS)

QoS is the overall needed performance of a network, such as accessibility, availability, latency, reachability, Jitter, MTBF (mean time between failures), etc.

The operation of an NCS is to communicate data from one node to another. The QoS of a network is a multidimensional parameterized measure of how well the network executes this job; the parameter measures include the speed and bandwidth of a network (how much data can be transmitted in a time interval), the delay and jitter associated with data transmission (time for a message to reach its destination, and repeatability of this time), and the reliability and security of the NCS infrastructure. When using NCS for automation, it is frequently important to evaluate determinism as a QoS parameter, specifically assessing whether message end-to-end communication times can be foreseen exactly or approximately and whether these times can be delimited. (Parrott J. T., Moyne J. R., and Tilbury D. M., 2006)

Using NCSs at level one in industrial automation can be seen as providing an adequate QoS, where quality in this range stands for guaranteed bandwidth with low and bounded network-induced latency and jitter.

Increase Productivity and Safe Operation

Safe operation means the protection of humans and machines against the hazards caused by incorrect functioning including communication via heterogeneous networks. There are several Safety Integrity Levels (SIL). The collection of safety standards has motivated industrial automation end users to look for open and exchangeable NCSs solutions that will improve the

integral safety of the plant while rendering increased information needed for asset management and optimization.

A SIL is the needed safety system performance grounded on risk assessment of a specific Safety Instrumented Function (SIF). SILs define the extent to which end users anticipate the process in question to perform safely or, in the case of a failure, fail in a safe manner.

No individual product within a SIF can carry a SIL rating; rather, individual components of processes, such as field devices, can only be certified as appropriate for use in given SIL environments.

A strong relation available between safety and increasing the productivity, as in the safety for humans, will reduce the accidents. This will lead to fewer absence and greater availability of staff; additionally, safety of the machines will reduce the possibility of stoppages and this will lead to increasing productivity.

2.4. Network Control System Evaluation

At the end, the goal of choosing the NCS should be to present business gains to the end users, whether the end user is looking for faster commissioning, better diagnostics, better performance, or increased system integrity.

Today we are losing expertise, energy costs are raising, and production requests are increasing. We require more than distributed controls. We need to manage our NCSs carefully, which will solve a bigger problem. It is important to link what you expect from distributed controls to added features, like increased alarm management, wireless integration, greater security, and embedded advanced applications, all built around abnormal situation management technology. Also important is the choosing of NCSs transparently integration device, sensor, and diagnostic information. These will all help to raise our operation effectiveness, increase process performance, improve our asset effectiveness, and accelerate our industrial business.

Reliability

Reliability is the confidence that what is sent by a node is received by its intended recipient.

Reliability is important because the outcome of lost messages can be missing data, missed events, or slow response times. It can be measured by counting the number of missed messages. Some networks are physically more vulnerable than others to data corruption by electromagnetic

interference. In addition, some networks use handshaking by sending acknowledgment messages to increase the reliability. If no acknowledgment message is received, the message is resent. These handshaking techniques can increase the reliability of a network, but they also add to the required overhead and thus decrease the overall effective bandwidth. Effective reliability will affect the overall reliability of an automation system, and this will affect the overall reliability of the plant. (Parrott J. T., et al, 2006)

Stability

With level one NCS technology now greatly recognized around the world, leading automation suppliers, integrators, and manufacturers are offering a wide selection of innovative NCS solutions helping customers achieve a more stable system, more ability to connect more instruments to their NCS. Some NCS suppliers utilize the level one NCS safe concept techniques to provide more stability and power on bus networks.

Performance

A proper message transmission protocol is essential to confirm the network QoS, whereas advanced controller design is desirable to confirm the control quality of performance (QoP). There are broad assortments of different commercially available control networks such as Ethernet, ControlNet, DeviceNet, Profibus, etc., for the implementation of NCS architecture. During the NCS design, a performance chart can be made. This performance chart provides a clear way to choose the proper sampling period for an NCS. The comparison of control performance versus sampling period for continuous control, digital control, and networked control. The bad, unsatisfactory, satisfactory, and acceptable regions can be introduced based on control system specifications such as overshoot, steady-state error, and/or phase margin. The performance axis could be selected to reflect a subset of these metrics. Since the performance of continuous control is not a function of the sampling period, the performance index is constant for a fixed control law. For the digital control case, the performance is only based on the sampling period assuming no other uncertainties. The performance debasement point of sampling period in digital control could be judged depending on the relationship between the control system bandwidth and the sampling rate. For the networked control case, point can be found by additionally looking into the characteristics and statistics of network-induced delays and device processing time delays. As the sampling period becomes smaller, the network traffic load gets heavier, the possibility of more contention time or data loss increases in a bandwidth-limited

network, and longer time delays result. This case makes the existence of Point with better performance and smaller sampling period in an NCS. (Lian F.L., et al , 2002)

Reduce Maintenance Cost

Choosing the correct NCS that is suitable for your application will reduce engineering, wiring, and component costs, and enable faster commissioning through standard coding, reduced errors, and improved error diagnosis. NCSs are more capable of change in terms of wiring, information flow, maintenance, and so on. Choosing the NCS suitable for your application not only reduces the cost of wiring. It also communicates a lot of information in an intelligent way, and improves remote monitoring, real-time self-diagnostics, predictive maintenance of field devices, as well as plant resource management using field communication. This will lead to a reduction in the operating costs of instrumentation systems.

2.5. Lessons Learned

This section provides the lessons learned from the literature reviewed.

Selecting the suitable NCS will provide the basics necessary for a plant's asset management capabilities.

End users can now select any protocol that could suit their application from a pool of available NCSs.

Their selection can affect the cost and performance, so it is important to understand the differences between different available NCSs before making a major investment.

Managing NCSs is fundamental to effective and efficient system operations. It will save time and money through scheduling maintenance appropriately and more effectively using the assets that are available.

The selection of NCS used and the chosen hardware will help to improve the system performance and stability

Offers include service aspects - not just technical aspects

The service aspects are important, just like the technical aspects in our case (NCSs), where it is critical for end users or customers (non-technical staff) like the management to decide for the future of their industry and for their investments to be in the correct track. So offers should not ignore these aspects and should deal with them as with the technical aspects.

The type of time delay could possibly reduce a system's performance and may cause system instability.

All industrial sectors are looking for ways to increase their productivity by having a stable system, high efficiency, high reliability, and by reducing the time and cost of maintenance. One of the major points that have a direct effect on these issues is how you select your NCS from the available pool of NCSs.

Users (industrial sector) should be considered as a part of the end-to-end system implementation

The practical feedback is quite important in order to offer better and more practical NCS, so end users should be considered as the basic component of the implementation circle, where sometimes there is a difference between theory and the practical life.

Control performance is important for safe operation

Safety for humans and for machines is one of the key success issues for increasing the performance and then increasing productivity by reducing the cost. It is true that a minimum number of accidents for workers and machines will reduce the number of stoppages for workers and machines. This will lead to cost reduction so there is a strong relation between performance and safe operation; selecting the NCS for level one in industrial automation is critical to guarantee safe operation.

Gap in criteria and analysis (mostly technical articles were found and not management ones)

There have been great deals of literature and much research dealing with the technical NCS, which was not the case of the management view.

3. RESEARCH METHOD

Research design and method are presented in this chapter. Section 3.1 provides the unit of analysis used in this research. Section 3.2 identifies the sample used. Section 3.3 shows the method of websites searched. And, finally, section 3.4 includes the method followed in this research.

3.1. Unit of Analysis

The unit of analysis is the companies who manufacture supplies or integrate automation products for the time period of June 2009.

3.2. Sample

The following standards were followed to choose the sample:

- Companies that were listed as IA manufactures, suppliers, or integrators as of June 2009.
- Companies that had more than 15 pages in their websites. (Hicks et al., 2006)

3.3. Keyword Search Tool

The web search method used by Hicks et al. (2006) and Opoku (2005) will be used to generate the deliverables.

A list of IA websites and a list of keywords are provided to the Keywords searching tool, the result was the number of occurrences of each keyword/website and the percentage of pages /website as well .The keyword search tool uses the Google (2008b) AJAX application programmer interface. The keyword search tool interface that was used in this research is shown in the next figure (figure 2)

Figure 2. The interface of keyword search tool

3.4. Choice of Research Method

- Qualitative data
- Non – orthogonal expect cross loadings, but better than alternatives of straight to cluster analysis. Orthogonal rotations produce factors that are uncorrelated; oblique methods allow the factors to correlate. (See APPENDIX D: ARTS OF FACTOR ANALYSIS)

3.5. Research Method

The research method used the following steps:

1. Introduce a list of keywords that will be used in the keyword search tool
2. Use the keyword search tool to collect data from the websites of industrial automation companies as manufactures or suppliers or integrators
3. Polish the raw data matrix resulted from step 2
4. Execute factor analysis on the polished data matrix
5. Construe the factors with eigenvalues greater than one.

Introduce a list of keywords

Initial keywords were selected by manually examining IA websites of the selected 15 companies from the list of IA websites.

Keywords considered important for the interactions of IA companies with NCSs were selected as the initial keywords.

Collect data by using the keyword search tool

A list of IA websites and a list of keywords were provided to the keywords searching tool; the result was the number of occurrences of each keyword/website.

The tool gives back an occurrences matrix that includes the number of hits for each keyword on each website. (A hit is defined as a page that includes the keyword that was used in searching.)

Polish the raw data matrix

The raw data matrix is manually analyzed and polished. Omnipresent keywords (those keywords presented everywhere at once on almost all of the sample websites) and keywords with few occurrences were taken away.

The method for polishing data matrix was first to initial Keywords entered to collect data and analyze the results; if a keyword is rare or omnipresent it will be removed and data will be collected again. After that, if analysis shows fewer than 35 keywords, additional key words from the websites will be added and the search repeated until the keyword set is acquired. The next figure (figure 3) shows the method for polishing the data matrix.

Figure 3. Flow sheet for polishing data matrix

Factor analysis on the polished data matrix

The practices defined in Darlington (2007) and Costello and Osborne (2005) were used and the maximum likelihood method used to extract factors, where the data gathered is normally distributed. Keywords with low Shapiro-Wilk normality test and little or no variances were dropped and removed from the analysis.

In the event that the data collected is normally distributed, the maximum likelihood method will be used to extract factors. If the data is skewed substantially, alpha extraction will be applied to the data. Varimax rotation was used in order to produce an orthogonal set of interpretable dimensions and uncorrelated factors

Costello, A., et.al (2005) 0.32 considered as a good rule of thumb for the minimum loading of an item, which equates to approximately 10% overlapping variance with the other items in that factor. 0.32 or higher on two or more factors. The researcher needs to decide whether a crossloading item should be dropped from the analysis, which may be a good choice if there are several adequate to strong loaders (.50 or better) on each factor. If there are several crossloaders, the items may be poorly written or the a priori factor structure could be flawed

Factors with eigenvalues greater than 1

All factors with eigenvalues greater than 1.0 were retained for rotation

4. RESULTS

This section includes the data analysis outcomes executed using the software package.

(The open source R language and environment for statistical computing and its graphical user interface (GUI) – the R Commander.)

4.1. Sample

The sample contains 214 industrial automation manufacturers, integrators, and suppliers. The list of industrial automation companies along with their website location and type of IA Company is in (APPENDIX B. LIST OF INDUSTRIAL AUTOMATION COMPANIES IN THE SAMPLE)

4.2. Keywords

Keywords were initially selected by manually examining the IA websites of 15 companies selected from the list of IA websites and from literature by identifying the criteria that differentiate NCSs.

Key words thought to represent the interactions of a company with NCS were selected as the initial keywords. Initially, a total of 45 keywords were identified.

4.3. Descriptive Statistics

Table 2 below presents the descriptive statistics for the initial 45 keywords

Table 2. Descriptive statistics for 45 variables representing the initial keywords (sample size = 214)

	Variable	Min	Max	Mean	Std. Dev.	Median	Normality test
1	Level One Industrial Automation OR Fieldbus	0	100	3.652	11.999	0.0053	0.3368
2	Ethernet OR Industrial Ethernet OR Industrial-Ethernet OR real time Ethernet system	0	100	18.329	23.767	7.269	0.7701
3	Modbus OR Mod-Bus OR Industrial ModBus OR ModBus	0	100	11.519	20.361	1.06	0.6327

	Variable	Min	Max	Mean	Std. Dev.	Median	Normality test
4	PROFINET OR Profi-Net OR Industrial ProfiNet OR ProfiNet	0	82.890	1.9040	8.4995	0.0021	0.238
5	Local Area Network OR Industrial LAN OR LAN	0	32.222	3.9136	6.0933	1.9209	0.6375
6	Low cost	0	34.848	3.0942	4.5775	2.0678	0.6005
7	Lower maintenance costs	0	9.6154	0.0934	0.6972	0.0007	0.1109
8	Maintainability	0	5.5556	0.1558	0.6174	0.0108	0.2658
9	Economy	0	20.426	1.993	2.5882	1.292	0.6799
10	high availability	0	9.6059	0.3732	1.1196	0.1141	0.3499
11	open	0	158.87	14.069	17.553	9.405	0.6315
12	High-Speed OR Fast start up on site OR fast start-up	0	23.077	2.4988	3.4632	1.2825	0.6724
13	Totally Integrated Automation OR TIA	0	11.905	0.4383	1.4579	0.0907	0.2847
14	Compatibility	0	35.610	3.4361	5.6857	1.299	0.6036
15	Security OR Secured bus system	0	104.48	10.175	14.914	5.078	0.6312
16	Reliability OR maximize productivity OR Increasing productivity	0	101.61	6.824	10.492	3.806	0.5654
17	Quality of communication OR Quality standards	0	3.7736	0.2618	0.4731	0.1861	0.552
18	Performance	0	102.18	16.393	15.793	11.416	0.8394
19	Efficiency	0	40.044	5.346	6.9646	2.796	0.7127
20	Flexibility OR Very versatile	0	31.371	5.017	5.3272	3.009	0.8126
21	Safety	0	174.10	10.127	15.906	5.963	0.5299
22	Wireless communication OR radio communication	0	4.6154	0.0743	0.3481	0	0.1695
23	Wireless fieldbus OR wireless network control systems OR Real time wireless	0	0	0	0	0	Identical
24	Communication failure	0	3.3333	0.1007	0.3696	0.0014	0.2972
25	Fail safe mode	0	4.5071	0.0297	0.3107	0	0.0673

	Variable	Min	Max	Mean	Std. Dev.	Median	Normality test
26	Handle multiple protocols on the same network	0	0.2591	0.0012	0.0178	0	0.0418
27	Factory industry standard	0	0	0	0	0	Identical
28	Unlimited network size	0	0.6993	0.0033	0.0479	0	0.0418
29	Reduce design cost	0	0.0480	0.0003	0.0033	0	0.0465
30	Easier integration OR simple to implement	0	0.9383	0.0276	0.1130	0.0038	0.2489
31	Digital communication	0	1.6105	0.0540	0.1699	0.0098	0.3145
32	Short cycle time	0	0.1012	0.0024	0.0111	0	0.2151
33	Powerful	0	40.808	4.1482	5.5288	1.976	0.7151
34	Open standard	0	3.8552	0.1242	0.3855	0.0091	0.3454
35	Message prioritization	0	0.5076	0.0052	0.0408	0	0.1099
36	Adjustable	0	37.225	3.006	5.3719	0.8107	0.5755
37	Over long distance	0	0.6061	0.0060	0.0449	0	0.1072
38	Varied field of application	0	0.0001	0.0001	1.95E-06	0	0.5963
39	Increased throughput	0	7.3171	0.1103	0.6263	0.0038	0.1677
40	Flexibility in vendor selection	0	1	0.0000	2.16E-06	0	0.5971
41	PROFIBUS.OR.ProfiBus .OR.Profi.Bus	0	0	0	0	0	Identical
42	DeviceNet	0	0	0	0	0	Identical
43	Controller.Area.Network. OR.CAN	0	0	0	0	0	Identical
44	WAN.OR.Wide.Area.Network	0	0	0	0	0	Identical
45	DirectNET	0	0	0	0	0	Identical

Alpha Extraction was used as the extraction method where the data breaks the status of normality. The next table (Table 3) presents the number of pages on IA companies' website. descriptive statistics.

Table 3. The number of pages on IA companies' website. descriptive statistics
(sample size = 214)

	Min	Max	Mean	Std. Deviation	Median
Total Web Sites size	0	3,540,000,000	1,191,000,000	1,676,541,488	4,635

4.4. Factor Analysis

The practices defined in Darlington (2007) and Costello and Osborne (2005) were used; the maximum likelihood method was used to extract factors, where the data gathered is normally distributed. Keywords with low Shapiro-Wilk normality test and little or no variances were dropped and removed from the analysis.

Fifteen variables were removed because they were identical and had a negative effect on the value of the Shapiro-Wilk normality test. The variables dropped were lower maintenance costs, wireless communication or radio communication, wireless fieldbus or wireless network control systems or real time wireless, fail safe mode, handle multiple protocols on the same network, factory industry standard, unlimited network size, reduce design cost, message prioritization, over long distance, Profibus.OR.ProfiBus., DeviceNet, Controller Area Network OR CAN, WAN OR Wide Area Network, and DirectNET.

Thirteen variables were removed because they did not efficiently differentiate choosing networks control systems or the protocol. The value of the Shapiro-Wilk normality test increased after they were dropped. These variables included the following keywords: level one industrial automation or Fieldbus, PROFINET or Profi-Net OR Industrial ProfiNet OR ProfiNet, Maintainability, high availability, Totally Integrated Automation or TIA, Communication failure, easier integration or simple to implement, Digital communication, Short cycle time, Open standard, varied field of application, increased throughput, Flexibility in vendor selection.

As a final result, the total of 45 variables was reduced to 17 variables, which were used in the factor analysis, by dropping 28 variables. 214/17 (IA companies to keywords) was the subject to item ratio. This is greater than the requisite minimum of 2/1.

The next table (Table.4) presents the initial and extraction percentage of variances for the variables commonalities used in the factor analysis. The initial one stands for the percentage of

variance in the variable explained by all of the variables. The extracted one stands for the percentage of variance in the variable explained by the extracted factors.

Table 4. Initial and extraction percentage of variances for the variables commonalities used in factor analysis (sample size = 214)

	Variable	% of Variances Initial	% of Variances Extraction
1	Ethernet OR Industrial Ethernet OR Industrial-Ethernet OR real time Ethernet system	0.2641	0.654
2	Modbus OR Mod-Bus OR Industrial ModBus OR ModBus	0.3022	0.141
3	Local Area Network OR Industrial LAN OR LAN	0.2805	0.914
4	Low cost	0.2639	0.786
5	Economy	0.2523	0.908
6	open	0.3962	0.335
7	High-Speed OR Fast start up on site OR fast start-up	0.2696	0.462
8	Compatibility	0.3687	0.583
9	Security OR Secured bus system	0.2434	0.837
10	Reliability OR maximize productivity OR Increasing productivity	0.398	0.492
11	Quality of communication OR Quality standards	0.1621	0.705
12	Performance	0.3744	0.245
13	Efficiency	0.2	0.688
14	Flexibility OR Very versatile	0.3787	0.429
15	Safety	0.2379	0.59
16	Powerful	0.4193	0.545
17	Adjustable	0.0688	0.904

Next table (table 5) shows the results of the Kaiser-Meyer-Olkin (KMO) and Bartlett's Test. The values for the sample data both fall within the acceptable range.

Table 5. Adequacy and Bartlett's test (sample size = 214)

Sampling adequacy	0.797
Chi-Square	1227.449
df	213
Sig	0

Figure 4 presents the Scree plot for industrial automation companies with 214 sample size (eigenvalues) of the extracted factors. Six factors had eigenvalues greater than 1. This test also correlates with that used by Costello and Osborne (2005). They used a scree plot analysis to decide the number of factors to retain (see APPENDIX D: ARTS OF FACTOR ANALYSIS)

Figure 4. Scree plot for industrial automation companies (sample size = 214)

The next table (Table.6) presents the sum of squared loadings where we found that 62.08% of the sample's total variance was explained by the six extracted factors.

Table 6: Sum of squared loading (sample size = 214)

Factor	Sums Of Squared Loadings		
	Total	% of Variances	% Cumulative
1	3.4188	20.11	20.11
2	1.8612	10.95	31.06
3	1.4942	8.79	39.85
4	1.4188	8.35	48.2
5	1.2761	7.51	55.71
6	1.0836	6.37	62.08

The next table (Table.7) presents the factor analysis results for the six factors solution. Only variables with factor loadings greater than 0.350 are shown in the table; the rest are removed. The rotations meet in seven iterations, the rotation method used Varimax with Shapiro-Wilk normality test, and Alpha Factoring was used as the extraction method

Table 7. Results of Factor Analysis (sample size = 214)

Variable		Factor Loadings					
		1	2	3	4	5	6
		Key features	Two NCSs	Performance & reliability	Important features	Safety and open	One NCS
17	Adjustable						
8	Compatibility	0.619					
5	Economy						
13	Efficiency				0.469		

Variable		Factor Loadings					
		1	2	3	4	5	6
		Key features	Two NCSs	Performance & reliability	Important features	Safety and open	One NCS
1	Ethernet OR Industrial Ethernet OR Industrial-Ethernet OR real time Ethernet system		0.535				
14	Flexibility OR Very versatile	0.336			0.673		
7	High Speed OR Fast start up on site OR fast start up	0.655					
3	Local Area Network OR Industrial LAN OR LAN						0.788
4	Low cost		0.351				
2	Modbus OR Mod Bus OR Industrial ModBus OR ModBus		0.960				
6	open					0.627	
12	Performance			0.848			
16	Powerful	0.588					
11	Quality of communication OR Quality standards				0.521		
10	Reliability OR maximize productivity OR Increasing productivity			0.556			
15	Safety					0.741	
9	Security OR Secured bus system			0.275*			0.268*

* Cross loadings will be kept

4.5. Summary of the Results Applied to the 214 Industrial Automation Companies

By studying the websites of the 214 Industrial automation companies we were able to code them based on the results of the factor analysis. The next table (Table.8) shows company classifications and type by factor. An X in one of the six factor columns means that the company interacts with the variables in the manner described by the factor.

Table 8. Identification and classification (sample size = 214)

Company name	Type	F1	F2	F3	F4	F5	F6	Code
National Instruments	Manufacturer	X				X		15
Automation Direct	Supplier	X						1
GE FANUC	Manufacturer	X			X	X	X	1456
OPTO 22	Manufacturer	X						1
WAGO Corporation	Manufacturer		X	X	X	X		2345
BECKHOFF	Manufacturer	X		X				13
CyperLogic	Supplier	X		X				13
Molex	Manufacturer		X			X		25
SoftPLC Corporation	Manufacturer	X	X				X	126
DataForth	Manufacturer		X					2
InvenSys Process System	Integrator	X	X	X	X			1234
Tek Supply	Supplier	X						1
Mass Group	Integrator	X			X	X	X	1456
Control Microsystems	Manufacturer	X			X	X	X	1456
ABB Industries LLC	Manufacturer			X				3
ATSI	Integrator	X	X					12
Control Technology Corporation	Manufacturer	X	X	X	X			1234
INTEG Process Group, Inc.	Integrator			X	X			34
KEP - Kessler-Ellis Products	Manufacturer	X	X					12
Keyence Corporation of America	Manufacturer						X	6
Wonderware West	Integrator			X				3
VIPA Automation	Manufacturer				X			4
ProSoft Technology	Manufacturer	X	X					12
ADVANTECH Automation	Integrator	X		X			X	136
RedLion	Manufacturer	X				X		15
Ctec Products	Supplier			X		X	X	356
RTA Automation	Integrator	X				X	X	156
MKS technology for productivity	Manufacturer		X	X	X	X		2345
Softing AG Automation	Supplier			X				3
CalAMP	Integrator	X			X	X	X	1456
Mu Dynamica	Integrator			X		X	X	356
WeidMuller	Manufacturer	X			X	X	X	1456
Cognet Real-Time system	Integrator			X			X	36
KY LAND	Manufacturer			X			X	36
s.I.TECH	Manufacturer	X					X	16
ACCES I/O Products, Inc	Manufacturer	X	X	X	X			1234
Comtech Holdings	Integrator		X	X	X		X	2346
Control Corporation	Manufacturer	X		X			X	136
DataLink Technologies Group, Inc.	Supplier	X					X	16
GarrettCom Europe Ltd	Manufacturer				X	X	X	456

Company name	Type	F1	F2	F3	F4	F5	F6	Code
HMS Industrial Networks Inc	Integrator	X	X				X	126
Kalki Communication Technologies Private Limited	Integrator		X		X		X	246
Program4 Engineering, Inc. - Coatesville, PA	Integrator			X	X		X	346
Advanced Machining and Automation, Inc. - Mount Pleasant, IA	Integrator	X						1
ATS Automation Tooling Systems - Cambridge, ON CAN	Integrator	X			X	X		136
A and B Process Systems - Stratford, WI Manufacturer	Integrator					X		5
Macron Dynamics, Inc. - Croydon, PA Manufacturer	Manufacturer						X	6
Istech, Inc. - York, PA	Integrator				X			4
Advantech	Integrator	X						1
Dixon Automatic Tool, Inc. - Rockford, IL	Manufacturer				X	X		45
Buflovak, LLC - Buffalo, NY Manufacturer	Integrator			X				3
Yaskawa Electric America, Inc., Switch Div. - Waukegan, IL	Manufacturer				X	X		45
Nol-Tec Systems, Inc. - Lino Lakes, MN	Supplier				X			4
ATC Automation Tool Co. - Cookeville, TN	Integrator			X	X			34
PaR Systems - Shoreview, MN	Supplier				X	X		45
CDS Manufacturing - Rochester, NY	Manufacturer				X			4
Bastian Material Handling - Indianapolis, IN	Integrator				X	X		45
Vaccon Co., Inc. - Medway, MA	Manufacturer	X	X	X	X			1234
Acro Automation Systems, Inc. - Milwaukee, WI	Integrator	X						1
Assembly and Automation Technology, Inc. - Woburn, MA	Manufacturer	X						1
ATI Industrial Automation - Apex, NC	Supplier				X	X	X	456
Buckeye Machine Fabricators, Inc. - Forest, OH	Integrator				X			4
Fastrak Technologies, Inc. - Rockford, IL	Integrator		X					2
Phoenix Contact - Middletown, PA	Manufacturer			X				3
Dartronics, Inc. - Perth Amboy, NJ	Integrator	X			X			14
Innovative Systems Engineering Inc. - Warminster, PA	Manufacturer	X			X	X		145

Company name	Type	F1	F2	F3	F4	F5	F6	Code
Weld-Action Co., Inc. - Warren, OH	Manufacturer			X				3
Unico, Inc. - Franksville, WI	Manufacturer	X			X		X	136
Applied Motion Products	Manufacturer					X		5
GBI Data Sorting Systems, Inc. - Deerfield Beach, FL	Integrator				X			4
PrimeTest Automation - Boca Raton, FL	Integrator	X		X			X	136
Baumer Electric	Manufacturer				X			4
Easom Automation Systems, Inc. - Madison Heights, MI	Integrator				X	X	X	456
G2 Technologies - Apex, NC	Integrator						X	6
Triad Automation Group, Inc. - Winston-Salem, NC	Manufacturer					X		5
Scott-Randall Systems, Inc. - Batavia, OH	Integrator	X			X			14
Doerfer Companies - Waverly, IA	Manufacturer						X	6
Numatic Engineering - Sun Valley, CA	Manufacturer	X						1
Vistamation, Inc. - Fallbrook, CA	Supplier				X	X		45
Erhardt and Leimer Inc, Linear Bearings Div - Duncan, SC	Manufacturer					X		5
Barrington Automation - Lake In The Hills, IL	Manufacturer				X	X		45
KIM Automation	Integrator				X	X		45
CimQuest INGEAR - Phoenixville, PA	Integrator		X					2
Delta Sigma Corp. - Kennesaw, GA	Manufacturer	X			X	X		145
Chemtrol	Manufacturer			X				3
PICS INC - MALVERN, PA	Supplier		X		X		X	246
Parker	Manufacturer	X	X	X	X			1234
Rockwell automation	Manufacturer					X		5
ATS Automation	Integrators				X			4
LEONI	Integrators					X		5
Industrial101	Integrators					X		5
Ultra Tech Machinery - Automation	Manufacturer				X			4
Industrial Automation	Supplier		X					2
Sterner Automation	Integrator	X			X			14
Rutter HInz	Integrator					X	X	56
BP Automation	Manufacturer						X	6
FF-Automation	Manufacturer		X				X	26
Shelley Automation	Manufacturer					X		5
Industrial leaders	Supplier	X						1
ACKSYS Communications and Systems	Integrator						X	6
Acromag	Manufacturer	X	X	X	X			1234

Company name	Type	F1	F2	F3	F4	F5	F6	Code
Cirronet	Manufacturer	X	X				X	126
Control Techniques	Manufacturer		X					2
ASCON Corporation	Manufacturer	X	X				X	126
Automated Solutions, Inc.	Supplier	X		X			X	136
Crouzet	Manufacturer	X						1
TOFINO Inc.	Manufacturer		X	X	X		X	2346
Connect Blue AB	Supplier			X			X	36
Control Solutions, Inc.	Manufacturer		X			X		25
Control Techniques - Americas, LLC	Manufacturer	X	X	X	X			1234
Danfoss Drives A/S	Manufacturer		X					2
Everest Software LLC	Supplier		X	X				23
FieldServer Technologies	Manufacturer	X			X	X	X	1456
Guangzhou ZHIYUAN Electronics Co., Ltd.	Manufacturer		X				X	26
Hilscher GmbH	Manufacturer		X					2
HMS Industrial Networks AB	Manufacturer	X	X				X	126
Ingeteam Corporación, S.A.	Integrator					X		5
Intellicom Innovation AB	Integrator	X	X				X	126
Crydom	Integrator		X					2
Korenix Technologies Co., Ltd.	Manufacturer	X			X	X	X	1456
Matrikon Inc.	Integrator		X	X		X		235
MESCO Engineering GmbH	Integrator			X				3
Motor Protection Electronics	Manufacturer				X			4
Moxa Connectivity Co., Ltd	Manufacturer		X		X		X	246
MYNAH Technologies	Supplier	X		X			X	136
Niobrara Research and Development Corp.	Manufacturer	X			X	X	X	1456
NIVUS GmbH	Supplier						X	6
Open Control Solutions	Manufacturer		X		X		X	246
PCN Technology, Inc.	Integrator				X			4
Phoenix Contact	Manufacturer					X	X	56
Precision Digital Corporation	Manufacturer	X	X				X	126
Schneider Electric SA	Manufacturer		X	X	X		X	2346
Sealevel Systems, Inc.	Manufacturer	X						1
Spectrum Controls	Manufacturer	X			X	X	X	1456
Spinwave Systems, Inc.	Manufacturer		X	X	X		X	2346
Sunlux Technologies Ltd.	Integrator	X	X	X	X			1234
Wachendorff Prozesstechnik GmbH and Co. KG	Manufacturer		X				X	26
ABB Automation Technologies	Manufacturer					X		5
Action Instruments	Supplier				X	X		45
ADFweb.com S.r.l.	Manufacturer	X	X					12
Adroit Technologies	Integrator			X		X	X	356

Company name	Type	F1	F2	F3	F4	F5	F6	Code
AGILiCOM	Integrator		X					2
EUROTECH	Manufacturer	X		X			X	136
Afcon Software and Electronics Ltd.	Supplier					X	X	56
B&B Electronics Mfg. Co.	Manufacturer	X			X	X	X	1456
Emerson	Manufacturer		X	X	X		X	2346
Bachmann electronic	Integrator						X	6
Bihl+Wiedemann GmbH	Manufacturer		X		X		X	246
Calta Computer Systems Ltd	Integrator		X		X		X	246
Cimetrics Inc.	Manufacturer	X		X				13
Custom Automation, Inc.	Integrator	X						1
Electric EATON	Manufacturer	X		X			X	136
DAE Instrument	Manufacturer		X	X		X		235
Data and Design Enterprises, Inc.	Integrator		X					2
Encoder Products Company	Manufacturer	X			X	X	X	1456
DCI Technologies	Manufacturer	X			X	X	X	1456
Deutschmann Automation GmbH and Co. KG	Manufacturer	X						1
OPC HMI and SCADA open automation software	Integrator	X				X		15
Embedded Solutions	Integrator		X			X		25
Equustek Solutions Inc	Manufacturer		X		X		X	246
EXEMYS	Manufacturer		X				X	26
Frontline Test Equipment, Inc.	Manufacturer	X	X					12
Industrial Control Communications, Inc.	Manufacturer		X	X	X	X		2345
Interface Concept	Manufacturer	X		X				13
Leroy Automatique Industrielle	Manufacturer					X		5
Smar UK Ltd	Integrator			X				3
Fincor	Manufacturer				X			4
Avanceon	Integrator			X				3
Max System	Integrator		X	X		X		235
Hammond Manufacturing	Manufacturer							5
Cornerstone Controls	Integrator					X	X	56
Hammond Power Solutions	Manufacturer					X		5
RTS Automation	Integrator			X	X			34
Inor	Integrator			X		X		35
Jumo	Supplier	X			X	X	X	1456
AME Tek	Manufacturer			X	X			34
Sensocon	Manufacturer	X		X				13
Anixter Inc.	Supplier			X			X	36
Sunx	Integrator	X						1
Unitronics	Manufacturer	X	X	X	X			1234
West	Manufacturer	X			X	X	X	1456

Company name	Type	F1	F2	F3	F4	F5	F6	Code
Tempco	Manufacturer	X			X	X	X	1456
Eaton	Supplier	X	X	X	X			1234
SensorTech	Manufacturer			X	X			34
Flow Serve	Supplier	X	X	X	X			1234
Gray Bar	Supplier	X	X	X	X			1234
Saftronics	Manufacturer			X		X		35
Honeywell.	Manufacturer			X		X		35
Precision Digital	Manufacturer			X		X		35
Lincoln	Manufacturer			X		X	X	356
KEP Kessler-Ellis Products	Manufacturer	X		X				13
Aromat	Supplier			X			X	36
Leeson	Integrator	X	X	X	X			1234
Juniper	Supplier	X				X	X	156
Intmet	Integrator	X			X			14
Maxim-Ic	Supplier			X	X			34
Molex	Supplier		X					2
Lovato Electric	Manufacturer			X		X	X	356
Infilink HMI	Manufacturer	X		X				13
Industrial Computing	Manufacturer			X				3
Dynisco	Manufacturer	X		X				13
Christensen Display Products	Manufacturer				X			4
Parker	Manufacturer				X			4
Bison Gear and Engineering Corporation	Manufacturer	X		X			X	136
CBI	Manufacturer					X		5
Raytheon	Integrator	X			X	X	X	1456
Rockwell automation	Manufacturer	X	X	X	X			1234
Valcor	Manufacturer			X				3
Tel Labs	Manufacturer	X				X	X	156
Texas Instruments	Supplier	X			X		X	136
Partlow	Manufacturer			X				3
Viatran	Manufacturer		X	X				23
SIEMENS	Manufacturer					X		6
RST Automation	Integrator		X					2

The next table (Table 9) presents the number of companies that share the same codes as well as a description of each code.

Table 9. Number of IA companies by Code (sample size = 214)

Code	Description	Number of companies	%
1	IA companies concentrate on the following keywords in choosing the NCS: compatibility, flexibility high speed and fast start up, and powerful	14	6.5 %
2	IA companies recommend using Modbus or Ethernet as the protocol for level one IA, which reduces the cost with ignoring security.	12	5.6%
3	IA companies concentrate on the following keywords in choosing the NCS : performance and reliability or maximize productivity or increasing productivity and the efficiency of protocol used	13	6.1%
4	IA companies concentrate on the following keywords in choosing the NCS: to be flexible or very versatile and concentrate on quality of communication or quality standards and should be efficient	13	6.1%
5	IA companies believe that in choosing NCS it is important to be open and satisfies safety for human and machines	14	6.5%
6	IA companies recommend using a LAN as the protocol for level one IA which maximizes the security for the bus system with ignoring quality of communication or quality standards and adjustability.	9	4.2%
12	IA companies recommend using Modbus or Ethernet as the protocol for level one IA, which reduces the cost, compatibility, flexibility high speed and fast start up, and powerful with ignoring security.	5	2.3%
13	IA companies concentrate on the following keywords in choosing the NCS: compatibility, flexibility , high speed and fast start up, powerful, performance and reliability or maximize productivity or increasing productivity and the efficiency of protocol used	8	3.7%
14	IA companies concentrate on the following keywords in choosing the NCS: compatibility, flexibility, high speed and fast start up, and powerful, to be flexible or very versatile and concentrate on quality of communication or quality standards and should be efficient	4	1.7%
15	IA company concentrates on the following keywords in choosing the NCS: compatibility, flexibility high speed and fast start up, and powerful, to be open and satisfies safety for human and machines	3	1.4%

Code	Description	Number of companies	%
16	IA companies recommend using the LAN as the protocol for level one IA which maximizes the security for the bus system, compatibility, flexibility high speed and fast start up, and powerful with ignoring quality of communication or quality standards and adjustability	2	0.9%
23	IA companies recommend using Modbus or Ethernet as the protocol for level one IA, which reduces the cost, performance and reliability or maximize productivity or increasing productivity and the efficiency of protocol used with ignoring security	2	0.9%
25	IA companies recommend using Modbus or Ethernet as the protocols for level one IA, which reduces the cost, opens and satisfies safety for human and machines, with ignoring security.	3	1.4%
26	IA companies recommend using Modbus or Ethernet or LAN as the protocols for level one IA, which maximizes the security for the bus system , and will reduce the cost	4	1.7%
34	IA companies concentrate on the following keywords in choosing the NCS: performance and reliability or maximize productivity or increasing productivity and the efficiency of protocol used , to be flexible or very versatile and concentrate on quality of communication or quality standards and should be efficient	6	2.8%
35	IA companies concentrate on the following keywords in choosing the NCS: performance and reliability or maximize productivity or increasing productivity and the efficiency of protocol used , it is important to be open and satisfies safety for human and machines	4	1.7%
36	IA companies recommend using the LAN as the protocol for level one IA which maximizes the security for the bus system, increase performance and reliability or maximize productivity or increasing productivity and the efficiency of protocol used with ignoring quality of communication or quality standards and adjustability.	5	2.3%
45	IA companies concentrate on the following keywords in choosing the NCS: to be flexible or very versatile and concentrate on quality of communication or quality standards and should be efficient , it is important to be open and satisfies safety for human and machines	8	3.7%

Code	Description	Number of companies	%
56	IA companies recommend using the LAN as the protocol for level one IA which maximizes the security for the bus system, open and satisfies safety for human and machines with ignoring quality of communication or quality standards and adjustability.	4	1.7%
156	IA companies recommend using the LAN as the protocol for level one IA which maximizes the security for the bus system, open and satisfies safety for human and machines, compatibility, flexibility high speed and fast start up, and powerful with ignoring quality of communication or quality standards and adjustability	3	1.4%
145	IA companies concentrate on the following keywords in choosing the NCS: to be flexible or very versatile and concentrate on quality of communication or quality standards and should be efficient , it is important to be open and satisfies safety for human and machines , compatibility, flexibility high speed and fast start up, and powerful	2	0.9%
126	IA companies recommend using Modbus or Ethernet or LAN as the protocols for level one IA, which maximizes the security for the bus system , and will reduce the cost, compatibility, flexibility high speed , fast start up, and powerful	7	3.3%
136	IA companies recommend using the LAN as the protocol for level one IA which maximizes the security for the bus system, increase performance and reliability or maximize productivity or increasing productivity and the efficiency of protocol used, compatibility, flexibility high speed and fast start up, and powerful with ignoring quality of communication or quality standards and adjustability	11	5.1%
246	IA companies recommend using the LAN or Modbus or Ethernet as the protocols for level one IA which maximizes the security for the bus system, flexibility and quality of communication or quality standards, efficiency, and will reduce the cost	7	3.3%
235	IA companies recommend using Modbus or Ethernet as the protocol for level one IA, which reduces the cost, increases performance and reliability or maximize productivity or increasing productivity and the efficiency of protocol used, open and satisfies safety for human and machines , with ignoring security	3	1.4%

Code	Description	Number of companies	%
356	IA companies recommend using the LAN as the protocol for level one IA which maximizes the security for the bus system, open and satisfies safety for human and machines, performance and reliability or maximize productivity or increasing productivity and the efficiency of protocol used with ignoring quality of communication or quality standards and adjustability	5	2.3%
346	IA companies recommend using the LAN as the protocol for level one IA which maximizes the security for the bus system, flexibility , quality of communication or quality standards ,increase efficiency, performance and reliability or maximize productivity or increasing productivity and with ignoring adjustability	1	0.47%
456	IA companies recommend using the LAN as the protocol for level one IA which maximizes the security for the bus system, open and satisfies safety for human and machines, flexible , quality of communication or quality standards and increase efficiency with ignoring adjustability	3	1.4%
1234	IA companies recommend using Modbus or Ethernet as the protocol for level one IA, which reduces the cost, compatibility, flexibility , high speed and fast start up, powerful , increase performance and reliability or maximize productivity or increasing productivity and the efficiency , and improve quality of communication or quality standards with ignoring security	14	6.5%
2345	IA companies recommend using Modbus or Ethernet as the protocol for level one IA, which reduces the cost, increase performance and reliability or maximize productivity or increasing productivity and the efficiency , flexibility and improve quality of communication ,open and satisfies safety for human and machines with ignoring security.	4	1.7%
1456	IA companies recommend using the LAN as the protocol for level one IA which maximizes the security for the bus system, open and satisfies safety for human and machines, flexible , quality of communication and increase efficiency compatibility, flexibility high speed and fast start up, and powerful with ignoring adjustability	17	7.9%
2346	IA companies recommend using the LAN or Modbus or Ethernet as the protocols for level one IA, which will reduce the cost , maximizes the security for the bus system, flexibility , improve quality of communication or quality standards ,increase efficiency, performance and reliability or maximize productivity or increasing productivity and with ignoring adjustability	4	1.7%

5. DISCUSSION OF RESULTS

This chapter will discuss the results in four sections. First, section 5.1 will discuss the Factors Interpretation. The second section, 5.2, will explain Company Clustering. The third section, 5.3, will introduce IA companies clustered by types. The last section, 5.4, will compare the Results with Companies Websites

5.1. Factors Interpretation

The next table (Table 10) presents the six factors with greater than one eigenvalues and the meaning according to the way that factor loadings interact with the keyword.

Table 10. Factors Interpretation (sample size = 214)

Factor	Name	Interpretation	Description
1	Key features	A group of IA companies as manufacturers, integrators, and suppliers believes that the most important key words in choosing the NCS which suits your application are : compatibility, flexibility high speed and fast start up, and powerful	Compatibility: Totally Integrated Automation (TIA), compatible with TCP/IP, and different other protocols and different levels for flexible PC communications. Support a virtually unlimited number of I/O points High speed and fast start up: Fast start-up by most simple wiring methods, improves the response capability, enables high-speed data exchange between the I/O and controllers, allowing fast start-up and troubleshooting, fast assembly, and faster commissioning. Powerful: efficient communication networks with a wide range, allow users to adjust the required performance within the network to their exact requirements, open and rugged bus system for process and field communication.

Factor	Name	Interpretation	Description
2	Two network control systems	A group of IA companies as manufacturers, integrators, and suppliers recommends using Modbus or Ethernet as the protocol for level one IA, which will reduce the cost with ignoring security.	<p>Modbus: particular protocol gains enough acceptance to be considered industry standard</p> <p>Ethernet : industry-standard communication protocols and sometimes called an industrial Ethernet</p> <p>Reduce the cost: no investment risk, lower maintenance costs, reduce design cost, spare parts costs, installation costs, decreasing commissioning time, saving money and time during planning, installation, commissioning, operation, and maintenance of the installation, reduced life cycle costs</p>
3	Performance & reliability	A group of IA companies as manufacturers, integrators, and suppliers believes that the most important key words in choosing the NCS which best suits your application are: performance and reliability or maximize productivity or increasing productivity and the efficiency of protocol used	<p>Performance and reliability or maximize productivity or increasing productivity and the efficiency : fast, easy, flexible, ease of use, remote access, open and rugged bus system, high plant availability, requiring much less space and fewer components, possible long-term product quality</p>
4	Important features	A group of IA companies as manufacturers, integrators, and suppliers believes that the most important key words in choosing the NCS which best suits your application are: to be flexible or very versatile and concentrate on quality of communication or quality standards and should be efficient	<p>Flexible or very versatile : easy-to-use, improves performance and enables support of other protocols, short cycle time, open communications standard, combine all aspects of enterprise management with process management into one network, and its ability to handle multiple protocols on the same network medium</p> <p>Quality of communication or quality standards: meet all your communication needs, no dropouts or blockage, increase uptime and maximize design flexibility,</p> <p>Improve mean-time-to- repair, reduce miscommunications, fulfills all the real-time demands relevant to the automation.</p> <p>Efficient: easy network setup, configuration, and troubleshooting, and choose the data rate as required</p>

Factor	Name	Interpretation	Description
5	Safety and open	A group of IA companies as manufacturers, integrators, and suppliers believes that the most important key words in choosing the NCS which best suits your application are, it is important to be open and satisfies safety for human and machines	Open: works with all the field point, interoperable, interchangeable, open standard, meaning that a customer can choose products from different vendors, provide connectivity to a wide variety of industrial networks, can be expanded without any problems, supports almost any topology, and true open architecture communication Safety: fail-safe mode, Intrinsic Safety (IS) requirements (for hazardous areas), inclusive safety concept for Personnel, machines, and the environment.
6	One Network control system	A group of IA companies as manufacturers, integrators, and suppliers recommends using LAN as the protocol for level one IA which maximizes the security for the bus system with ignoring quality of communication or quality standards and adjustability.	LAN: communication protocol for process control sensors, actuators, and control devices Security: protection against data espionage and data manipulation, protection against overloading the communication system, two-way influence protection and address errors. Fulfills the increased requirements for data and network security.

5.2. Company Clusters

The companies clustered in two different ways, first by offer code as described in table 9 and shown in table 11. Table 11 presents the code, number of companies, and the percentage as well as the name of companies included. The second way according to their types

Figure 5. IA companies clustered according to above mentioned classification (sample size = 214)

Table 11. IA companies clustered by offer code described in table 9 (sample size = 214)

Code	Companies Included	# of companies	Percentage
1	Automation Direct , / OPTO 22 / Tek Supply / , Advanced Machining and Automation, Inc. - Mount Pleasant, IA / Advantech / Acro Automation Systems, Inc. - Milwaukee, WI / Assembly and Automation Technology, Inc. - Woburn, MA / Numatic Engineering - Sun Valley, CA / Industrial leaders / Crouzet / Sealevel Systems, Inc. / Custom Automation, Inc. / Deutschmann Automation GmbH and Co. KG / Sunx	13	6.1 %
2	DataForth , / Fastrak Technologies, Inc. - Rockford, IL / CimQuest INGEAR - Phoenixville, PA / Industrial Automation / Control Techniques / Danfoss Drives A/S // Hilscher GmbH / Crydom / AGILiCOM / Data and Design Enterprises, Inc. / Molex / RST Automation	12	5.6 %
12	ATSI , / KEP - Kessler-Ellis Products / ProSoft Technology / ADFweb.com S.r.l. / Frontline Test Equipment, Inc.	5	2.3
15	RedLion , / OPC HMI and SCADA open automation software	2	0.9
13	BECKHOFF / CyperLogic / Cimetrics Inc. / Interface Concept / Sensicon / KEP Kessler-Ellis Products / Infilink HMI / Dynisco	8	3.7
14	Dartronics, Inc. - Perth Amboy, NJ / Scott-Randall Systems, Inc. - Batavia, OH / Sterner Automation / Intmet	4	1.9
3	ABB Industries LLC / Wonderware West / Softing AG Automation / Buflovak, LLC - Buffalo, NY Manufacturer / Phoenix Contact - Middletown, PA / Weld-Action Co., Inc. - Warren, OH / Chemtrol / MESCO Engineering GmbH / Smar UK Ltd / Avanceon / Industrial Computing / Valcor / Partlow	13	6.1
26	FF-Automation / Guangzhou ZHIYUAN Electronics Co., Ltd. / Wachendorff Prozesstechnik GmbH & Co. KG / EXEMYS	4	1.9
23	Everest Software LLC / Viatran	2	0.9
35	Inor / Safronics / Honeywell. / Precision Digital	4	
4	VIPA Automation , / Istech, Inc. - York, PA / Nol-Tec Systems, Inc./ - Lino Lakes, MN / CDS Manufacturing - Rochester, NY / Buckeye Machine Fabricators, Inc. - Forest, OH / GBI Data Sorting Systems, Inc. - Deerfield Beach, FL / Baumer Electric / ATS Automation / Ultra Tech Machinery - Automation / Motor Protection Electronics / PCN Technology, Inc. / Fincor / Christensen Display Products / Parker	15	7

Code	Companies Included	# of companies	Percentage
16	s.I.TECH / DataLink Technologies Group, Inc./	2	0.9
45	Dixon Automatic Tool, Inc. - Rockford, IL / Yaskawa Electric America, Inc./ Switch Div. - Waukegan, IL / PaR Systems - Shoreview, MN / Bastian Material Handling - Indianapolis, IN / Vistamation, Inc. - Fallbrook, CA / Barrington Automation - Lake In The Hills, IL / KIM Automation / Action Instruments	9	4.2
25	Molex / Control Solutions, Inc. / Embedded Solutions	3	1.4
156	RTA Automation / Juniper / Tel Labs	3	1.4
34	INTEG Process Group, Inc. / ATC Automation Tool Co. - Cookeville, TN / RTS Automation / AME Tek / SensorTech / Maxim-Ic	6	2.8
126	SoftPLC Corporation , /HMS Industrial Networks Inc , / Cirronet / ASCON Corporation / HMS Industrial Networks AB / Intellicom Innovation AB / Precision Digital Corporation	7	3.3
145	Innovative Systems Engineering Inc. - Warminster, PA / Delta Sigma Corp. - Kennesaw, GA	2	0.9
356	Ctec Products , /Mu Dynamica / Adroit Technologies / Lincoln / Lovato Electric	5	2.3
36	Cognet Real-Time system , / KY LAND / Connect Blue AB / Anixter Inc. / Aromat	5	2.3
246	Kalki Communication Technologies Private Limited , / PICS INC - MALVERN, PA / Moxa Connectivity Co., Ltd / Open Control Solutions / Bihl+Wiedemann GmbH / Calta Computer Systems Ltd / Equustek Solutions Inc	7	3.3
56	Rutter HInz / Phoenix Contact / Afcon Software and Electronics Ltd. / Cornerstone Controls	4	1.9
456	GarrettCom Europe Ltd , / ATI Industrial Automation - Apex, NC / Easom Automation Systems, Inc. - Madison Heights, MI	3	1.4
235	Matrikon Inc. / DAE Instrument / Max System	3	1.4
2345	WAGO Corporation , / MKS technology for productivity / Industrial Control Communications, Inc.	3	1.4
15	National Instruments	1	0.5
136	ADVANTECH Automation , / Control Corporation , / ATS Automation Tooling Systems - Cambridge, ON CAN/ Unico, Inc. - Franksville, WI / PrimeTest Automation - Boca Raton, FL / Automated Solutions, Inc. / MYNAH Technologies / EUROTECH / Electric EATON / Bison Gear and Engineering Corporation / Texas Instruments	11	5.1
2346	Comtech Holdings / TOFINO Inc. / Schneider Electric SA / Spinwave Systems, Inc. / Emerson /	5	2.3

Code	Companies Included	# of companies	Percentage
1234	InvenSys Process System ,/ Control Technology Corporation ,/ ACCES I/O Products, Inc/ Vaccon Co., Inc. - Medway, MA / Parker / Acromag / Control Techniques - Americas, LLC / Sunlux Technologies Ltd. / Unitronics / Eaton / Flow Serve / Gray Bar / Leeson / Rockwell automation	14	6.5
6	Keyence Corporation of America , / Macron Dynamics, Inc. - Croydon, PA Manufacturer / G2 Technologies - Apex, NC / Doerfer Companies - Waverly, IA / BP Automation / ACKSYS Communications and Systems /NIVUS GmbH / Bachmann electronic / SIEMENS /	9	4.2
5	A and B Process Systems - Stratford, WI Manufacturer/Applied Motion Products / Triad Automation Group, Inc. - Winston-Salem, NC / Erhardt & Leimer Inc, Linear Bearings Div - Duncan, SC / Rockwell automation / LEONI / Industrial101 / Shelley Automation / Ingeteam Corporación, S.A. / ABB Automation Technologies / Leroy Automatique Industrielle / Hammond Manufacturing / Hammond Power Solutions / CBI	14	6.5
1456	GE FANUC ,/ Mass Group , /Control Microsystems , CalAMP ,/ WeidMuller , / FieldServer Technologies / Korenix Technologies Co., Ltd. / Niobrara Research & Development Corp. / Spectrum Controls / B&B Electronics Mfg. Co. / Encoder Products Company / DCI Technologies / Jumo / West / Tempco / Raytheon	15	7
346	Program4 Engineering, Inc. - Coatesville, PA	1	0.5

Based on the code offer and description, the clustering of IA companies can be grouped as follows:

Features: concentrates on specific features in choosing the network control system for level one in industrial automation applications.

Eighty-nine IA companies (manufacturers, integrators, suppliers), (42%), doesn't include any exact preferable protocol to be use for level one in IA, just offered a specific key word which was important for the end users to satisfy before selecting the NCS .

Those include the following codes: 1, 3, 4, 5, 13, 14, 15, 34, 35, 45, and 145.

Two NCSs: two NCSs (protocols) as the choice for level one in IA depending on usage

Forty-seven IA companies (manufacturers, integrators, suppliers), (22%), do include two preferable NCS (protocols) in their offer as the best choice for level one in IA, which are:

Modbus or Ethernet. They include the following codes: 2, 12, 23, 25, 26, 235, 1234, and 2345. Those protocols satisfy most of the key words and ignore some others, which are considered as non-important for the end users at this level; some examples are security, quality of communication, or quality standards and adjustability.

One NCS: One NCS (LAN) as the choice for level one in IA for all their offers

Sixty-four IA companies (manufacturers, integrators, suppliers), (30%), strongly recommended using a LAN as the best choice with great benefit for level one in industrial automation. They include the following codes: 6, 16, 36, 56, 156, 136, 356, 346, 456, and 1456. This protocol satisfy all the key words, including the security and ignores only two key words, which are considered as non-important for the end users at this level; some examples are quality of communication or quality standards .

Pool of NCSs: they include the three NCSs (protocols) as the best choice for level one in IA.

Only fourteen IA companies (manufacturers, integrators, suppliers), (6%), which includes the three preferable network control system (protocols) in their offer as the best choice for level one in IA, which are Modbus or Ethernet or LAN. They include the following codes: 126, and 246. The three protocols satisfy some of the key words and ignore some others, which are considered as non-important for the end users at this level.

5.3. IA companies clustered by types of company

Next in Table 12 shows the clustering of industrial automation companies according to their type: manufacturer, integrator, or supplier.

Table 12. IA companies clustered by types of company (sample size = 214)

Type of company	Number of companies	Codes Included
Manufacturer	119	1, 2, 3, 4, 5, 6, 12, 13, 15, 16, 25, 26, 34, 35, 36, 45, 56, 126, 136, 235, 246, 356, 456, 1234, 1456, 2345, 2346
Integrator	65	1, 2, 3, 4, 5, 6, 12, 13, 14, 15, 16, 23, 34, 35, 36, 45, 56, 136, 145, 156, 235, 246, 346, 356, 1234, 1456, 2346
Supplier	30	1, 2, 3, 4, 5, 6, 12, 13, 14, 15, 23, 25, 26, 34, 35, 36, 45, 56, 126, 136, 235, 246, 356, 456, 1234, 1456

Type one: Manufacturers,

One hundred and nineteen companies (56 %); this includes all the factors except the following factors 14, 23, 346, 145, and 156

Type two: Integrators,

Sixty five companies (30 %); this includes all the factors except the following: 25, 26, 126, 2345, 346, 26, and 25

Type three: Suppliers,

Thirty companies (14 %); this includes all the factors except the following: 2345, 145, 156, 2346, 346, and 16

Figure 6. IA companies clustered according to their types (sample size = 214)

The codes, which are not included and repeated with more than one type, include 346, 145, and 156

5.4. Comparing Results with Companies Websites

We can study if the IA companies describe accurately their variables with level one NCS on their websites by using the raw data returned from the keyword search tool.

The next table (Table 13) shows 23 out of 32 clusters from the sample for each of 214 IA companies' factor loadings. For each cluster, the percentage of pages with at least one of the keywords for its respective factor is presented. At the end of the table, the average percentage of pages is shown for each factor.

Table 13. IA companies factor loading clusters (sample size = 214)

Clusters	Factors					
	F1	F2	F3	F4	F5	F6
1	8%	34%	14%	9%		
4	8%	22%	13%			5%
12	6%	23%	12%	6%		
13	7%	19%	15%			
14	9%					
15	7%	19%				
16		19%				
23						
34	9%	20%	12%	8%	2%	
35	8%	19%	10%			
36			9%	8%	7%	
156	8%		10%			
145						1%
Clusters	Factors					
	F1	F2	F3	F4	F5	F6
136	16%					
246		20%	11%	10%	4%	
235			17%			
356	6%					
346						

456		19%		9%		
1234	7%		20%	11%	5%	
2345	9%					
1456						10%
2346	6%		10%	10%	3%	
Average	8%	21%	13%	9%	4%	3%

This data presented in the table shows how will IA companies represent their interactions with clusters on their websites. Some of the clusters don't show any interaction with all six factors; these clusters are 2, 3, 5, 6, 25, 26, 45, 56, and 126. Accordingly the rest of the factors interact with clusters as follows:

Factor 1: (the most important features in choosing the best NCS are compatibility, high speed and fast start up, powerful and flexible) looks well presented across most of the clusters except 16, 23, 36, 145, 246, 235, 346, 456, 1456.

On average, factor 1 is poorly presented compared to factors 2, 3, and 4 but differentiated.

Factor 2: (using Modbus or Ethernet as the protocol for level one IA, which will reduce the cost with ignoring security) looks very well presented across most of the clusters except 14, 23, 36, 156, 145, 136, 235, 356, 346, 1234, 2345, 1456, 2346.

On average, factor 2 is strongly presented compared to the other factors.

Factor 3: (the most important features in choosing the best NCS are performance and reliability or maximize productivity) looks very well presented across most of the clusters except 14, 15, 16, 23, 145, 136, 356, 346, 456, 2345, 1456.

On average factor 3 is well presented compared to the other factors.

Factor 4: (the most important features in choosing the best NCS: flexibility or very versatile and concentrates on quality of communication and efficiency) looks well presented across some of the clusters except 4, 13, 14, 15, 16, 23, 35, 156, 145, 136, 235, 356, 346, 2345, 1456.

On average, factor 4 is weakly presented compared to factors 2 and 3.

Factor 5: (the most important features in choosing the best NCS: to be open and satisfies safety for human and machines) looks poorly presented across some of the clusters and it doesn't appear in most of the clusters.

On average, factor 5 is weakly presented compared to factors 2 and 3.

Factor 6: (using LAN as the protocol for level one IA, which maximizes the security with ignoring quality of communication and adjustability) looks very poorly presented across some of the clusters and it doesn't appear in most of the clusters.

On average, factor 6 is very weakly presented compared to factors 2 and 3.

6. CONCLUSIONS

This chapter contains the following sections. Section 6.1 will introduce the conclusion of this research. Section 6.2 will present the limitations of this research and the last section, 6.3, will provide opportunities for future research.

6.1. General Conclusions

By using the data mining technique, this research classifies IA companies by the way they represent their offers with level one NCSs in IA on their websites.

The main conclusions that can be drawn from the results are:

1. IA Company websites render premium information that can be used to help the end users choose the NCS that best suits their application.
2. IA companies interact with NCSs in different ways:
 - (i) General features are used in choosing the network control system for level one in IA applications; as shown in Table 14.

Table 14. General features for selecting the best network control system for level one in IA applications

	Legend	Feature Description
1	C	Compatible
2	E	Efficiency
3	F	Flexible
4	H	High speed
5	O	Open
6	P	Performance
7	P	Powerful
8	Q	Quality standards
9	R	Reliable
10	S	Safety

- (ii) Low cost feature: a choice between two NCSs (protocols) for level one in IA (Low Cost feature).

Table 15. Low cost features for level one in industrial automation applications

Low cost NCSs	Legend	Satisfied Features	Ignored Features
		Description	
Modbus or Ethernet	C	Compatible	Security
	C	Cost	
	E	Efficiency	
	F	Flexible	
	H	High speed	
	O	Open	
	P	Performance	
	P	Powerful	
	Q	Quality standards	
	R	Reliable	
	S	Safety	

(iii) Security features: one NCS (protocol) as the secured choice for level one in IA.

Table 15. Security feature for level one in industrial automation applications

Secured NCS	Legend	Satisfied Features	Ignored Features
		Description	
Local Area Network(LAN)	E	Efficiency	Cost Quality standards and adjustability
	F	Flexible	
	H	High speed	
	O	Open	
	P	Performance	
	P	Powerful	
	R	Reliable	
	S	Safety	
	S	Security	

(iv) Specific features: choose between three NCSs (protocols) as the choice for level one in IA (Pool of NCSs)

Table 16. Specific features for level one in industrial automation applications

Pool Of NCSs	Legend	Satisfied Features	Ignored Features
		Description	
Modbus or Ethernet or LAN	C	Compatible	Security Quality standards and Adjustability
	C	Cost	
	E	Efficiency	
	F	Flexible	
	H	High speed	
	P	Performance	
	P	Powerful	
	R	Reliable	

3. Industrial applications could be divided as follows :

- (i) General applications NCS: which satisfies most of the features (example: chemical and automotive industry).
- (ii) Non-secured applications NCS: which mainly satisfies the low-cost installation and maintenance features, with ignoring the security at this level. (examples: food and beverage industry and building automation)
- (iii) Secured applications NCS: this protocol is requested for specific applications where the Security features are very important with ignoring the quality of communication feature (examples: energy industry, water and waste water industry).

4. The results show that there are no specific NCS that satisfied the need for security with quality of communication at this level of networking.

5. Based on the conclusions 2 & 3 of this research, figure 7 presents a selection guide that Could help the end users or customers to select the NCS that best suits their application:

The selection guide starts from the top, which goes down to divide for three branches; the user has to choose between these three selections according to his application (General application, or Secured application or non secured application).

Now a general application will guide you through two selections: either general or specific feature; again selecting between these two depends on the application.

For each one of these two selections a set of features (Key words) is satisfied or can be requested to satisfy.

The non-secured application selection will guide us through the low cost feature, which satisfies some features but security is not one of them.

The secured application selection, will guide us through a security feature where the security feature is satisfied or requested with ignoring the cost

Figure 7. A selection guide for the NCS in level one IA

6.2. Selection guide

The selection guide was built based on the conclusions and results from this research, where each level shown on the selection guide presented a conclusion from this research as follows :

Level C: common features:

Referring to table 17, eight features (keywords) are common between the three NCSs, Modbus, Ethernet and LAN. On another perspective, those features (keywords) are considered as specific features to be satisfied when choosing the NCS for your application. Some features are not shared (ignored) between the three NCSs, which are specific for each NCS like: security, quality standard and adjustability.

Level P: protocols:

Referring to table 17, a pool of NCSs presented to choose according to your application. So Modbus & Ethernet share the same features (keywords) which are different for LAN. Referring to table 15, Modbus & Ethernet, have twelve features are common for both of them and the specific feature for those two NCSs is the cost which differentiate from LAN, but the security feature ignored.

Referring to table 16, nine feature are presented for LAN –NCS, the unique feature for this protocol the security but the cost feature ignored.

Level K: Key words (features)

Referring to tables 14, 15, 16 & 17, we have six set of features (keywords), some features are common between all selections and some other is unique for specific selection.

KS1: Keywords set 1: it includes three features which are unique for general feature selection .

KS2: keywords set 2: it includes seven features which are common between general & specific feature selection

KS3: Keywords set 3: it includes one feature which is common between specific & low cost features selection

KS4: keywords set 4: it includes three features which are unique for low cost feature selection

KS5: Keywords set 5: it includes eight features which are common between low cost &

security features selections

KS 6: keywords set 6: it includes only one feature which is unique for security feature Selection

Level F: Features selections

Referring to tables 14, 15, 16, & 17, four features selection are presented which are, general, specific, low cost & security

Level A: applications selections

According to this research conclusions & results, three applications selections are presented, which are: general applications, non secured applications & secured applications

Level S: Start

This selection guide will help the end users for the features they have to select in order to get the optimum of their NCSs, as well as the conditions they have to consider when upgrading their NCS . It is clear that there are two major features that the customers have to care about when structuring thei NCS , which are : first the cost , where in this case the customer has to ignore the security for NCS , the second is inverse of that , which means that it the application needs security , then the cost will be high .

As there were very little previous research that discusses the management of NCSs, for level one IA, there were many surprises that are contrary to the researcher's experience in this field, for example, the inverse relation between cost and security , the using of Ethernet as a protocol in industry , and the use of LAN as the preferred secured protocol .

6.3. Limitations

The following are the limitations related to this research:

1. Reliance on public information related to NCS on the automation manufacturers, integrators, and supplier's companies' web sites – are not necessarily accurate indicators
2. Limited available literature dealing with management aspects for NCS in industrial Automation
3. There is a strong dependency on the selected keywords, different keywords could give different results
4. This research was able to include only English IA – companies' web sites (not all with

different languages)

6.4. Future Research Opportunities

1. Build an automated programmed selection tool based on the results of this research which makes the selection more easy and automated for the customers to choose the NCS which best suits their application.
2. Test the end users, or customer, opinions in relation to the best NCS for level one in IA and compare the results to these research results.
3. Investigate the reliability and usability of IA companies' public web sites.
4. Determine the criteria to choose the best programmable logic controller (PLC) or controller for IA.
5. Choosing the best protocol and hardware for second level network control system.

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8. APPENDICES

APPENDIX A. ACRONYMS AND GLOSSARY

CAN	Controller Area Network
Data networks	are qualified by big data packets, comparatively infrequent bursty communication, and high data rates; they generally do not have hard real-time constraints
Ethernet	Communication protocol
GUI	graphical user interface
IA	Industrial Automation
IS	Intrinsic Safety
Jitter	associated with data transmission (time for a message to reach its destination, and repeatability of this time)
LAN	Local Area Network
Level one industrial automation	the area starts from controllers or PLCs level & going down
ModBus	Communication protocol
MTBF	mean time between failures
NCS	Network Control System
Network control system	is a network for linking field devices such as sensors and actuators; field controllers such as PLCs, regulators, drive controllers, etc.; and man-machine interfaces
PLC	Programmable logic controller
Profibus	is a broadcast bus protocol that operates as a MultiMate/slave system
QoP	quality of performance
QoS	Quality of Service
Reliability	is the confidence that what is sent by a node is received by its intended recipient
Safe operation	means the protection of humans and machines against the hazards caused by incorrect functioning including communication via heterogeneous networks.

SIL	several Safety Integrity Levels
TCP/ IP	Transmission Control Protocol / Internet Protocol
Throughput	is defined as the amount of information that is carried by a network at a given time
TIA	Totally Integrated Automation
WAN	Wide Area Network

APPENDIX B. LIST OF INDUSTRIAL AUTOMATION COMPANIES IN THE SAMPLE

	Company name	Type	Web site Address
1	National Instruments	Manufacturer	http://www.ni.com/
2	Automation Direct	Supplier	http://www.automationdirect.com/
3	GE FANUC	Manufacturer	http://www.gefanuc.com/
4	OPTO 22	Manufacturer	http://www.opto22.com/
5	WAGO Corporation	Manufacturer	http://www.wago.us/
6	BECKHOFF	Manufacturer	http://www.beckhoffAutomation.com/
7	CyberLogic	Supplier	http://www.cyberlogic.com/
8	Molex	Manufacturer	http://www.woodhead.com/
9	SoftPLC Corporation	Manufacturer	http://www.softplc.com/
10	DataForth	Manufacturer	http://www.dataforth.com/
11	InvenSys Process System	Integrator	http://www.ips.invensys.com/
12	Tek Supply	Supplier	http://www.tek-supply.com/
13	Mass Group	Integrator	http://www.massgroup.com/
14	Control Microsystems	Manufacturer	http://www.controlmicrosystems.com/
15	ABB Industries LLC	Manufacturer	http://www.abb.ca/
16	ATSI	Integrator	http://www.atsi.cc/
17	Control Technology Corporation	Manufacturer	http://www.ctc-control.com/
18	INTEG Process Group, Inc.	Integrator	http://www.integpg.com/
19	KEP - Kessler-Ellis Products	Manufacturer	http://www.kep.com/
20	Keyence Corporation of America	Manufacturer	http://www.keyence.com/
21	Wonderware West	Integrator	http://208.109.28.191/
22	VIPA Automation	Manufacturer	http://www.vipa-usa.com/
23	ProSoft Technology	Manufacturer	http://www.ProSoft-Technology.com/
24	ADVANTECH Automation	Integrator	http://www.advantech.com/
25	RedLion	Manufacturer	http://www.redlion.net/
26	Ctec Products	Supplier	http://www.ctekproducts.com/
27	RTA Automation	Integrator	http://www.rtaautomation.com/
28	MKS technology for productivity	Manufacturer	http://www.mksinst.com/
29	Softing AG Automation	Supplier	http://www.softing.com/
30	CalAMP	Integrator	http://www.calamp.com/
31	Mu Dynamica	Integrator	http://www.mudynamics.com/
32	WeidMuller	Manufacturer	http://www.weidmuller.com/
33	Cognet Real-Time system	Integrator	http://www.opcdatahub.com/
34	KY LAND	Manufacturer	http://www.kyland.cn/
35	s.I.TECH	Manufacturer	http://www.sitech-bitdriver.com/
36	ACCES I/O Products, Inc	Manufacturer	http://www.accessio.com/

	Company name	Type	Web site Address
37	Comtech Holdings	Integrator	http://www.comtechm2m.com/
38	Comtrol Corporation	Manufacturer	http://www.comtrol.com/
39	DataLink Technologies Group, Inc.	Supplier	http://www.protocolconverter.com/
40	GarrettCom Europe Ltd	Manufacturer	http://www.garrettcom.co.uk/
41	HMS Industrial Networks Inc	Integrator	http://www.anybus.com/
42	Kalki Communication Technologies Private Limited	Integrator	http://www.kalkitech.com/
43	Program4 Engineering, Inc. - Coatesville, PA	Integrator	http://www.program4.com/
44	Advanced Machining and Automation, Inc. - Mount Pleasant, IA	Integrator	http://www.adv-mach.com/
45	ATS Automation Tooling Systems - Cambridge, ON CAN	Integrator	http://www.atsautomation.com/
46	A & B Process Systems - Stratford, WI Manufacturer	Integrator	http://www.abprocess.com
47	Macron Dynamics, Inc. - Croydon, PA Manufacturer	Manufacturer	http://www.macrondynamics.com/
48	Istech, Inc. - York, PA	Integrator	http://www.istech-inc.com/
49	Advantech	Integrator	http://www.advantech.com/
50	Dixon Automatic Tool, Inc. - Rockford, IL	Manufacturer	http://www.dixonautomatic.com/
51	Buflovak, LLC - Buffalo, NY Manufacturer	Integrator	http://www.buflovak.com/
52	Yaskawa Electric America, Inc., Switch Div. - Waukegan, IL	Manufacturer	http://www.yaskawa.com/
53	Nol-Tec Systems, Inc. - Lino Lakes, MN	Supplier	http://www.noltec.com/
54	ATC Automation Tool Co. - Cookeville, TN	Integrator	http://www.automationtool.com
55	PaR Systems - Shoreview, MN	Supplier	http://www.par.com/
56	CDS Manufacturing - Rochester, NY	Manufacturer	http://www.cdsmanufacturing.com/

	Company name	Type	Web site Address
57	Bastian Material Handling - Indianapolis, IN	Integrator	http://www.bastiansolutions.com/
58	Vaccon Co., Inc. - Medway, MA	Manufacturer	http://www.vaccon.com/
59	Acro Automation Systems, Inc. - Milwaukee, WI	Integrator	http://www.acro.com/
60	Assembly & Automation Technology, Inc. - Woburn, MA	Manufacturer	http://www.assemblyandautomationtech.com/
61	ATI Industrial Automation - Apex, NC	Supplier	http://www.ati-ia.com/
62	Buckeye Machine Fabricators, Inc. - Forest, OH	Integrator	http://www.buckeyemachine.com/
63	Fastrak Technologies, Inc. - Rockford, IL	Integrator	http://www.fastraktech.com/
64	Phoenix Contact - Middletown, PA	Manufacturer	http://www.phoenixcontact.com/
65	Dartronics, Inc. - Perth Amboy, NJ	Integrator	http://www.dartronics.com/
66	Innovative Systems Engineering Inc. - Warminster, PA	Manufacturer	http://www.iseonline.com/
67	Weld-Action Co., Inc. - Warren, OH	Manufacturer	http://www.weldaction.com/
68	Unico, Inc. - Franksville, WI	Manufacturer	http://www.unicous.com/
69	Applied Motion Products	Manufacturer	http://www.applied-motion.com/
70	GBI Data Sorting Systems, Inc. - Deerfield Beach, FL	Integrator	http://www.gbisorters.com/
71	PrimeTest Automation - Boca Raton, FL	Integrator	http://www.primetest.com/
72	Baumer Electric	Manufacturer	http://www.baumerelectric.com/
73	Easom Automation Systems, Inc. - Madison Heights, MI	Integrator	http://www.easomeng.com/
74	G2 Technologies - Apex, NC	Integrator	http://www.g2tek.com/
75	Triad Automation Group, Inc. - Winston-Salem, NC	Manufacturer	http://www.triadautomationgroup.com/
76	Scott-Randall Systems, Inc. - Batavia, OH	Integrator	http://www.scott-randallsystems.com/

	Company name	Type	Web site Address
77	Doerfer Companies - Waverly, IA	Manufacturer	http://www.doerfercompanies.com/
78	Numatic Engineering - Sun Valley, CA	Manufacturer	http://www.numaticengineering.com/
79	Vistamation, Inc. - Fallbrook, CA	Supplier	http://vistamation.com/
80	Erhardt & Leimer Inc, Linear Bearings Div - Duncan, SC	Manufacturer	http://www.erhardt-leimer.com/
81	Barrington Automation - Lake In The Hills, IL	Manufacturer	http://www.barringtonautomation.com/
82	KIM Automation	Integrator	http://www.kimautomation.com/
83	CimQuest INGEAR - Phoenixville, PA	Integrator	http://www.ingeardrivers.com/
84	Delta Sigma Corp. - Kennesaw, GA	Manufacturer	http://www.deltasigmacorp.com/
85	Chemtrol	Manufacturer	http://www.sbcontrol.com/
86	PICS INC - MALVERN, PA	Supplier	http://www.picscontrols.com/
87	Parker	Manufacturer	http://www.parkermotion.com/
88	Rockwell automation	Manufacturer	http://www.rockwellautomation.ca/
89	ATS Automation	Integrators	http://www.atsautomation.com/
90	LEONI	Integrators	http://www.leoni-automation-drives.com/
91	Industrial101	Integrators	http://www.industrial101.com/
92	Ultra Tech Machinery - Automation	Manufacturer	http://www.utmachinery.com/
93	Industrial Automation	Supplier	http://www.pptvision.com/
94	Sterner Automation	Integrator	http://www.sternerautomation.com/
95	Rutter HInz	Integrator	http://www.hinz.com/
96	BP Automation	Manufacturer	www.bpautomation.com
97	FF-Automation	Manufacturer	http://www.ff-automation.com/
98	Shelley Automation	Manufacturer	http://www.shelley.com/
99	Industrial leaders	Supplier	http://www.industrialleaders.com/
100	ACKSYS Communications & Systems	Integrator	http://www.acksys.com/
101	Acromag	Manufacturer	http://www.acromag.com/
102	Cirronet	Manufacturer	http://www.cirronet.com/
103	Control Techniques	Manufacturer	http://www.emersonct.com/
104	ASCON Corporation	Manufacturer	http://www.asconcorp.com/
105	Automated Solutions, Inc.	Supplier	http://www.automatedsolutions.com/
106	Crouzet	Manufacturer	http://www.crouzet.com/
107	TOFINO Inc.	Manufacturer	http://www.tofinosecurity.com/
108	Connect Blue AB	Supplier	http://www.connectblue.se/
109	Control Solutions, Inc.	Manufacturer	http://www.csimn.com/

	Company name	Type	Web site Address
110	Control Techniques - Americas, LLC	Manufacturer	http://www.emersonct.com/
111	Danfoss Drives A/S	Manufacturer	http://www.danfoss.com/
112	Everest Software LLC	Supplier	http://www.hmisys.com/
113	FieldServer Technologies	Manufacturer	http://www.fieldserver.com/
114	Guangzhou ZHIYUAN Electronics Co., Ltd.	Manufacturer	http://www.embedcontrol.com/
115	Hilscher GmbH	Manufacturer	http://www.hilscher.com/
116	HMS Industrial Networks AB	Manufacturer	http://www.hms-networks.com/
117	Ingeteam Corporación, S.A.	Integrator	http://www.ingetteam.com/
118	Intellicom Innovation AB	Integrator	http://www.intellicom.se/
119	Crydom	Integrator	http://www.crydom.com/
120	Korenix Technologies Co., Ltd.	Manufacturer	http://www.korenix.com/
121	Matrikon Inc.	Integrator	http://www.matrikonopc.com/
122	MESCO Engineering GmbH	Integrator	http://www.mesco.de/
123	Motor Protection Electronics	Manufacturer	http://www.mpelectronics.com/
124	Moxa Connectivity Co., Ltd	Manufacturer	http://www.moxa.com/
125	MYNAH Technologies	Supplier	http://www.mynah.com/
126	Niobrara Research & Development Corp.	Manufacturer	http://www.niobrara.com/
127	NIVUS GmbH	Supplier	http://www.nivus.com/
128	Open Control Solutions	Manufacturer	http://www.opencontrolsolutions.com/
129	PCN Technology, Inc.	Integrator	http://www.pcntechnology.com/
130	Phoenix Contact	Manufacturer	http://www.phoenixcontact.com/
131	Precision Digital Corporation	Manufacturer	http://www.predig.com/
132	Schneider Electric SA	Manufacturer	http://www.schneider-electric.com/
133	Sealevel Systems, Inc.	Manufacturer	http://www.sealevel.com/
134	Spectrum Controls	Manufacturer	http://www.spectrumcontrols.com/
135	Spinwave Systems, Inc.	Manufacturer	http://www.spinwavesystems.com/
136	Sunlux Technologies Ltd.	Integrator	http://www.sunlux-india.com/
137	Wachendorff Prozesstechnik GmbH & Co. KG	Manufacturer	http://www.wachendorff.de/
138	ABB Automation Technologies	Manufacturer	http://www.abb.com/
139	Action Instruments	Supplier	http://www.actionio.com/
140	ADFweb.com S.r.l.	Manufacturer	http://www.adfweb.com/
141	Adroit Technologies	Integrator	http://www.adroit.co.za/
142	AGILiCOM	Integrator	http://www.agilicom.fr/
143	EUROTECH	Manufacturer	http://www.arcom.co.uk/
144	Afcon Software and Electronics Ltd.	Supplier	http://www.afcon-inc.com/

	Company name	Type	Web site Address
145	B&B Electronics Mfg. Co.	Manufacturer	http://www.bb-elec.com/
146	Emerson	Manufacturer	Multi http://www.gotoemerson.com/
147	Bachmann electronic	Integrator	http://www.bachmann.info/
148	Bihl+Wiedemann GmbH	Manufacturer	http://www.Bihl-Wiedemann.com/
149	Calta Computer Systems Ltd	Integrator	http://www.calta.com/
150	Cimetrics Inc.	Manufacturer	http://www.cimetrics.com/
151	Custom Automation, Inc.	Integrator	http://www.CustomAutomation.com/
152	Electric EATON	Manufacturer	http://www.eatonelectrical.com/
153	DAE Instrument	Manufacturer	http://www.daeinstrument.com/
154	Data and Design Enterprises, Inc.	Integrator	http://www.dataanddesign.com/
155	Encoder Products Company	Manufacturer	http://www.encoder.com/
156	DCI Technologies	Manufacturer	http://www.dcitech.com/
157	Deutschmann Automation GmbH & Co. KG	Manufacturer	http://www.deutschmann.de/
158	OPC HMI and SCADA open automation software	Integrator	http://www.opcsystems.com/
159	Embedded Solutions	Integrator	http://www.embedded-solutions.at/
160	Equustek Solutions Inc	Manufacturer	http://www.equustek.com/
161	EXEMYS	Manufacturer	http://www.exemys.com/
162	Frontline Test Equipment, Inc.	Manufacturer	http://www.fte.com/
163	Industrial Control Communications, Inc.	Manufacturer	http://www.iccdesigns.com/
164	Interface Concept	Manufacturer	http://www.interfaceconcept.com/
165	Leroy Automatique Industrielle	Manufacturer	http://www.leroy-automation.com/
166	Smar UK Ltd	Integrator	http://www.SmarUK.co.uk/
167	Fincor	Manufacturer	http://www.safronics.com/
168	Avanceon	Integrator	http://www.avanceon.com/
169	Max System	Integrator	http://www.maxsys.com/
170	Hammond Manufacturing	Manufacturer	http://www.hammondmfg.com/
171	Cornerstone Controls	Integrator	http://www.cornerstonecontrols.com/
172	Hammond Power Solutions	Manufacturer	http://www.hammondpowersolutions.com/
173	RTS Automation	Integrator	http://www.rtsautomation.com/
174	Inor	Integrator	http://www.inor.com/
175	Jumo	Supplier	http://jumoplus.com/
176	AME Tek	Manufacturer	http://www.ametek.com/
177	Sensocon	Manufacturer	http://www.sensocon.com/
178	Anixter Inc.	Supplier	http://www.anixter.com/
179	Sunx	Integrator	http://www.sunx-ramco.com/
180	Unitronics	Manufacturer	http://www.unitronics.com/
181	West	Manufacturer	http://www.westinstruments.com/

	Company name	Type	Web site Address
182	Tempco	Manufacturer	http://www.tempco.com/
183	Eaton	Supplier	http://www.eaton.com/
184	SensorTech	Manufacturer	http://www.sensortecinc.com/
185	Flow Serve	Supplier	http://www.flowserve.com/
186	Gray Bar	Supplier	http://www.graybar.com/
187	Safronics	Manufacturer	http://www.safronics.com/
188	Honeywell.	Manufacturer	http://www.honeywell.com/
189	Precision Digital	Manufacturer	http://www.predig.com/
190	Lincoln	Manufacturer	http://www.lincolnmotors.com/
191	KEP Kessler-Ellis Products	Manufacturer	http://www.kep.com/
192	Aromat	Supplier	http://pewa.panasonic.com/
193	Leeson	Integrator	http://www.lesson.com/
194	Juniper	Supplier	http://www.juniper.net/
195	Intmet	Integrator	http://www.intmet.com/
196	Maxim-Ic	Supplier	http://www.maxim-ic.com/
197	Molex	Supplier	http://www.molex.com/
198	Lovato Electric	Manufacturer	http://www.lovatousa.com/
199	Infilink HMI	Manufacturer	http://www.kep.com/
200	Industrial Computing	Manufacturer	http://www.industcomputing.com/
201	Dynisco	Manufacturer	http://www.dynisco.com/
202	Christensen Display Products	Manufacturer	http://www.christensendisplay.com/
203	Parker	Manufacturer	http://www.parker.com/
204	Bison Gear and Engineering Corporation	Manufacturer	http://www.bisongear.com/
205	CBI	Manufacturer	http://www.cbibreakers.com/
206	Raytheon	Integrator	http://www.raytheon.com/
207	Rockwell automation	Manufacturer	http://www.rockwellautomation.com/
208	Valcor	Manufacturer	http://www.valcor.com/
209	Tel Labs	Manufacturer	http://www.tellabs.com/
210	Texas Instruments	Supplier	http://www.ti.com/
211	Partlow	Manufacturer	http://www.partlow.com/
212	Viatran	Manufacturer	http://www.viatran.com/
213	SIEMENS	Manufacturer	http://www.siemens.com/
214	RST Automation	Integrator	http://www.rtsautomation.com/

APPENDIX C: DESCRIPTIVE STATISTICS FOR 45 VARIABLES REPRESENTING THE INITIAL KEYWORD (SAMPLE SIZE = 214)

	Variable	Min	Max	Mean	Std. Dev.	Median	Normality test
1	Level One Industrial Automation OR Fieldbus	0	100	3.652	11.999	0.0053	0.3368
2	Ethernet OR Industrial Ethernet OR Industrial-Ethernet OR real time Ethernet system	0	100	18.329	23.767	7.269	0.7701
3	Modbus OR Mod-Bus OR Industrial ModBus OR ModBus	0	100	11.519	20.361	1.06	0.6327
4	PROFINET OR Profi-Net OR Industrial ProfiNet OR ProfiNet	0	82.890	1.9040	8.4995	0.0021	0.238
5	Local Area Network OR Industrial LAN OR LAN	0	32.222	3.9136	6.0933	1.9209	0.6375
6	Low cost	0	34.848	3.0942	4.5775	2.0678	0.6005
7	Lower maintenance costs	0	9.6154	0.0934	0.6972	0.0007	0.1109
8	Maintainability	0	5.5556	0.1558	0.6174	0.0108	0.2658
9	Economy	0	20.426	1.993	2.5882	1.292	0.6799
10	high availability	0	9.6059	0.3732	1.1196	0.1141	0.3499
11	open	0	158.87	14.069	17.553	9.405	0.6315
12	High-Speed OR Fast start up on site OR fast start-up	0	23.077	2.4988	3.4632	1.2825	0.6724
13	Totally Integrated Automation OR TIA	0	11.905	0.4383	1.4579	0.0907	0.2847
14	Compatibility	0	35.610	3.4361	5.6857	1.299	0.6036
15	Security OR Secured bus system	0	104.48	10.175	14.914	5.078	0.6312
16	Reliability OR maximize productivity OR Increasing productivity	0	101.61	6.824	10.492	3.806	0.5654
17	Quality of communication OR Quality standards	0	3.7736	0.2618	0.4731	0.1861	0.552
18	Performance	0	102.18	16.393	15.793	11.416	0.8394

	Variable	Min	Max	Mean	Std. Dev.	Median	Normality test
19	Efficiency	0	40.044	5.346	6.9646	2.796	0.7127
20	Flexibility OR Very versatile	0	31.371	5.017	5.3272	3.009	0.8126
21	Safety	0	174.10	10.127	15.906	5.963	0.5299
22	Wireless communication OR radio communication	0	4.6154	0.0743	0.3481	0	0.1695
23	Wireless fieldbus OR wireless network control systems OR Real time wireless	0	0	0	0	0	Identical
24	Communication failure	0	3.3333	0.1007	0.3696	0.0014	0.2972
25	Fail safe mode	0	4.5071	0.0297	0.3107	0	0.0673
26	Handle multiple protocols on the same network	0	0.2591	0.0012	0.0178	0	0.0418
27	Factory industry standard	0	0	0	0	0	Identical
28	Unlimited network size	0	0.6993	0.0033	0.0479	0	0.0418
29	Reduce design cost	0	0.0480	0.0003	0.0033	0	0.0465
30	Easier integration OR simple to implement	0	0.9383	0.0276	0.1130	0.0038	0.2489
31	Digital communication	0	1.6105	0.0540	0.1699	0.0098	0.3145
32	Short cycle time	0	0.1012	0.0024	0.0111	0	0.2151
33	Powerful	0	40.808	4.1482	5.5288	1.976	0.7151
34	Open standard	0	3.8552	0.1242	0.3855	0.0091	0.3454
35	Message prioritization	0	0.5076	0.0052	0.0408	0	0.1099
36	Adjustable	0	37.225	3.006	5.3719	0.8107	0.5755
37	Over long distance	0	0.6061	0.0060	0.0449	0	0.1072
38	Varied field of application	0	0.0001	0.0001	1.95E-06	0	0.5963
39	Increased throughput	0	7.3171	0.1103	0.6263	0.0038	0.1677
40	Flexibility in vendor selection	0	1	0.0000	2.16E-06	0	0.5971
41	PROFIBUS.OR.ProfiBus .OR.Profi.Bus	0	0	0	0	0	Identical
42	DeviceNet	0	0	0	0	0	Identical

	Variable	Min	Max	Mean	Std. Dev.	Median	Normality test
43	Controller.Area.Network. OR.CAN	0	0	0	0	0	Identical
44	WAN.OR.Wide.Area.Ne twork	0	0	0	0	0	Identical
45	DirectNET	0	0	0	0	0	Identical

APPENDIX D: ARTS OF FACTOR ANALYSIS

D.1. Introduction

Factor analysis is defined as a complicated process with little pure guidelines and many different options (Costello and Osborne, 2005). Many of these options have few or no accounts of their merits and demerits; they concentrate solely on when and why they should be used (Darlington, 2007). This deficiency of documentation and hard guidelines in relation to factor analysis has been branded as unscientific, and has been discredited because of the irreproducible results. In other words, factor analysis is used to detect shapes in the relationship through a number of variables. It specifically tries to explain these relationships using a much smaller set of variables called factors.

A successful factor analysis will provide answers to the following 4 questions:

1. How many different factors are required to explain the pattern of relationships among these variables?
2. What are the characteristics of those factors?
3. How well do the hypothesized factors explain the observed data?
4. How much purely random or unique variance does each observed variable include?"

(Darlington, 2007)

The judgment of factor analysis has been questioned due to the number of different results generated on the same data set by a number of different researchers. This does not mean that factor analysis is not objective, however. Researchers will make trade-offs differently as they select between simplicity (fewer factors) and accuracy (more factors). They may also differ in how they define their factors. (Darlington, 2007) mentioned that this will lead to multiple sets of correct solutions. This is very similar to algorithm development. When developing a particular algorithm, a software engineer must make trade-offs between simplicity and performance. Although five different engineers will almost certainly develop five different algorithms, it is also quite certain that all five will be correct.

Notorious Past Factor Analysis

During the 1950s, factor analysis was targeted not as one of the data analysis arts available, but as the only data analysis technique to use (Darlington, 2007). This overzealous promotion by a number of researchers led to the technique being over-used and misapplied. One specific wrong

use was seeking to qualify very wide sets of data, pushing the technique more than it is able to return accurate results. These factors, along with the complexity and lack of strict guidelines have led to factor analysis being suspected in some circumstances (Darlington, 2007). It is important to set out a concise method indicating how factor analysis will be used in order to ensure correct results and a defensible data set.

D.2. Best Practices examples

Factor analysis regards a multi-step way that lets the researcher select from a number of multiple techniques in each action. Costello and Osborne (2005) and Darlington (2007) suggested some of the best practices as follows:

1. Factor Analysis vs. Principal Component Analysis

The default extraction in most of the favourable statistics packages, principal component analysis (PCA), is not frequently the best method to use (Costello and Osborne, 2005; Darlington, 2007). It is the most popular extraction technique to use yet it is not a method of factor analysis using the classical definition. There is also a fair amount of disagreement about when PCA should and should not be used (Costello and Osborne, 2005). Due to that, Costello and Osborne recommend factor analysis over PCA. PCA is a data reduction method that was made popular when computing power was expensive. In PCA there is no discrimination between unique and shared variance. Factor analysis on the other hand differentiates shared variance from unique variance and error variance in bringing out the data sets underlying structure (Costello and Osborne, 2005). Factor analysis will result in the same solution as PCA, while at the same time avoiding the increase of variance by making use of a more complex algorithm that today's computers can handle with ease.

2. Methods of Extracting Factor

Costello and Osborne (2005) found that most statistics software packages have 6 or more factor extraction methods (PCA, unweighted least squares, generalized squares, maximum likelihood, principal axis factoring, alpha factoring and image factoring). This leads to confusion and usually to the use of PCA. Costello and Osborne have also outlined the best practices for choosing an extraction method.

They recommend that if the data set is normal, maximum likelihood is the best choice. The reason for this choice is because “[maximum likelihood] allows for the computation of a wide range of indexes of the goodness of fit of the model and permits statistical significance testing of factor loadings and correlations among factors and the computation of confidence intervals.” When the data is not normal, Costello and Osborne recommend the principal factor method (also referred to as principal axis factors).

3. Number of Factors to Retain

Selecting the number of factors is an important step in factor analysis. The higher the number of factors, the more complex the results will be to see; however, both Costello and Osborne (2005) and Darlington (2007) point out that it is sometimes necessary to use a larger set of factors in order to accurately reflect the relationships underlying the data set. It is important that the correct number of factors be maintained for rotation since both over extraction and under extraction will lead to incorrect results. Most software packages use very inaccurate method of choosing factors to retain: keeping all factors with eigenvalues greater than 1. Costello and Osborne state that this is inaccurate and will often lead to incorrect results. They recommend the scree test, which tends to be the most widely available of the three. In the scree test, the graph of eigenvalues is examined and the number of data points above the “break” in the graph becomes the number of factors to retain. After rotation, if the loading tables do not clearly show factors then there may be a problem with either the number of factors or the data itself. Removing the problematic items and re-running the analysis can help, but this can damage data integrity (Costello and Osborne, 2005). If, after multiple test runs, the data does not show a pattern, the data may need to be purged and new data collected. In Darlington (2007) use of the scree test is also recommended. As an alternative, Darlington (2007) recommends completing a complete factor analysis with various numbers of factors and selecting the one that has the most well-defined structure. Although more time and resource consuming, this will lead to the best results.

4. Sample Size

Although sample size tends to be a function of the strength of the data, a good rule of thumb is that it is always better to have more data (Costello and Osborne, 2005; Darlington, 2007).