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ŽIČ(A)NI/BEŽIČNI KOMUNIKACIONI MREŽNI MODEL U GRAĐEVINSKOM OKRUŽENJU: STUDIJA SLUČAJA RAFINERIJA ŠEĆERA BRČKO

WIRED/WIRELESS COMMUNICATION NETWORK MODEL IN BUILDING ENVIRONMENT: CASE-STUDY OF BRČKO SUGAR REFINERY

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APSTRAKT

Predmet istraživanja u okviru ovog rada su integrisane žične i bežične komunikacione tehnologije u procesnoj industriji, sa ciljem da se bude ukorak sa svjetskim trendovima u ovoj oblasti, a odnose se na sljedeće aktivnosti. Prvo će biti dat kratak pregled istorijskog razvoja i biće opisane tehničke karakteristike industrijskih protokola koji imaju najveću primjenu u industrijskim komunikacionim mrežama. Zatim će biti opisane neophodne faze za integrisanje bežične tehnologije unutar postojećeg postrojenja sa već instaliranim žičanim uređajima. Na kraju ovog rada biće predložena integracija bežičnih tehnologija u realizaciji industrijskih komunikacionih mreža, a koja će biti verifikovana analizom dobijenih rezultata u studiji opravdanosti za uvođenje modela integrisane mreže u realnom postrojenju u rafineriji šećera u Brčkom

Ključne riječi: *procesna industrija, automatizovani industrijski sistemi, fieldbus protokoli, WirelessHART protocol*

WIRED/WIRELESS COMMUNICATION NETWORK MODEL IN BUILDING ENVIRONMENT: CASE-STUDY OF BRČKO SUGAR REFINERY

ABSTRACT

The subject of the research within the scope of this paper is integrated wired and wireless communication technologies in the process industry, with the aim of keeping up with the world trends in this field, and refers to the following activities. First, a brief overview of the historical development will be provided and the technical characteristics of the industrial protocols that have the greatest application in industrial communication networks will be described. Then, necessary steps to integrate wireless technology within an existing facility with wired devices already installed will be presented. At the end of this paper, the integration of wireless technologies in implementing industrial communication networks will be proposed, which will be verified by analysing the results obtained in a feasibility study for introducing an integrated network model in a real facility in a sugar refinery in Brčko.

Keywords: *process industry, automated industrial systems*, *fieldbus protocols, WirelessHART protocol*

1. INTRODUCTION

Modern control systems in the process industry are increasingly using wireless data transmission to send out information from a sensor located directly at the site of process to the central control unit. There are numerous reasons for such an approach. The most common reason for choosing a wireless industrial communication network is the cost of installation since eliminating or significantly reducing cable usage means great savings in cable and installation work. In other words, the cost of new installation, maintenance and repair is lower than the corresponding cost for cable solutions, and thus wireless technology opens up a completely new field of application in terms of how measured process data is transmitted. Costs in wired networks can be even higher if there is a need to expand existing infrastructure in order to include additional measurements, while adding new measurement locations in wireless networks represents low costs and greatly reduces the economic barrier that exists in wired networks.

For the last few years, several of the world's leading manufacturers of process measuring equipment have focused on addressing these and other problems in industrial wireless networks [1, 2]. The result is the integration of wired and wireless communication technology based on the HART protocol, which can lead to significant cost reductions in manufacturing processes [3]. That is, when these technologies are integrated, they need to provide almost unlimited opportunities that range from monitoring and diagnostics of devices to controlling production processes.

2. DEVELOPMENT OF THE FIELDBUS PROTOCOL

Complex automated industrial systems usually require hierarchical control organisation as in Figure 1.

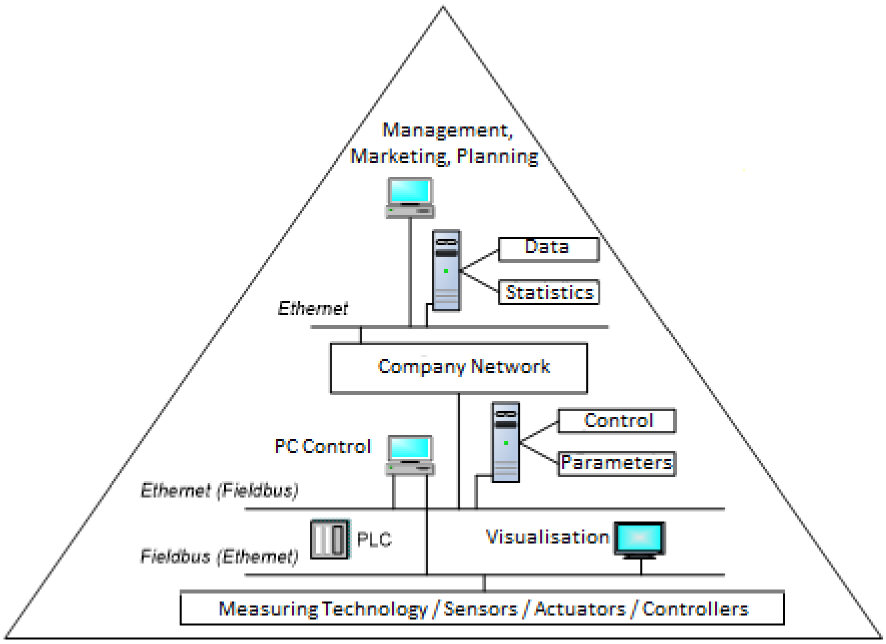

Figure 1. Pyramid of control organisation

Typically, the user interface is at the top of this hierarchy, where an operator can monitor or control the system. It is linked to the intermediate layer, consisting of the PLCs (Programmable Logic Controllers), via a non-time critical communication system, i.e. by Ethernet. At the bottom of the control chain is the Fieldbus that links the PLCs to executable components, such as, actuators, motors, etc. [4].

2.1. TECHNICAL FEATURES OF THE FIELDBUS PROTOCOL

Fieldbus technology provides improved quality, reduced costs and increased system efficiency [5]. These capabilities of fieldbus technology come partly from the fact that information received or transmitted by the device can be sent out digitally. Each device has a built-in processor unit, making it a "smart device" and capable of performing independently simple functions, such as maintenance and diagnostics [6]. As a result, it is possible to receive information if the device is defective or requires manual calibration. It increases the efficiency of the system and reduces requirements for system maintenance. The main advantage of implementing a fieldbus compared to the 4-20 mA standard is associated with reduced wiring since multiple devices share a wire pair in network communication. The disadvantages of using a fieldbus compared to the 4-20 mA standard are:

- Fieldbus systems are more complex, so the user has to be more qualified.
- The price of fieldbus components is higher.

One of the significant features of the fieldbus protocol is that it only includes three or four layers of OSI (Open Systems Interconnection) models, as shown in Figure 2:

- Physical Layer: Defines the communication medium and can be considered a replacement for the 4-20 mA standard.
- Data Link Layer: Defines communication between devices and fault detection.

- Application Layer: Designs messages so that each device on the network can understand them, serves them to process control, and forwards them to the user layer.
- User Layer: Connects individual parts and ensures an environment for applications.

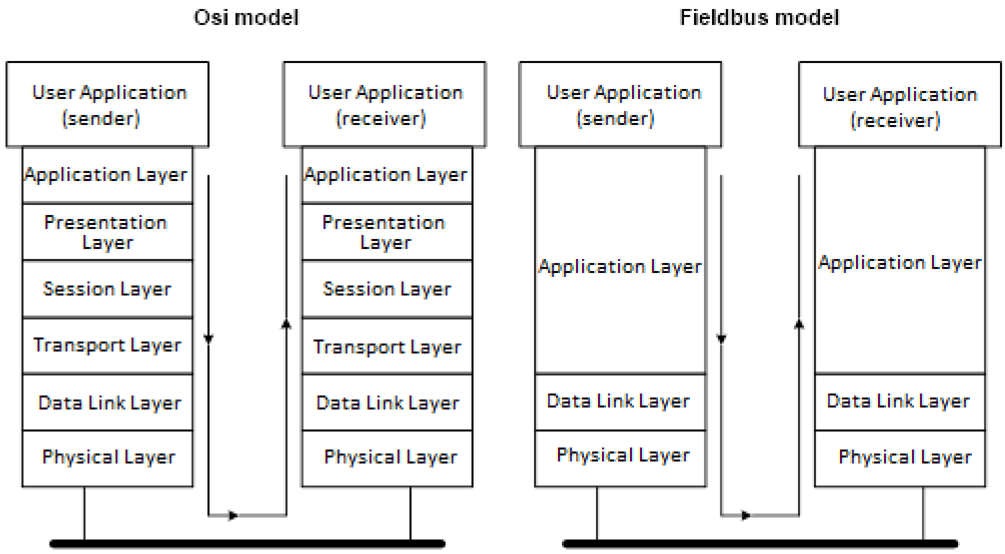

Figure 2. OSI Reference Model and Fieldbus Model

The advantage of fieldbus is that a user does not have to worry about the data link layer and the application layer, i.e. they only have to worry about the physical and user layer [1]

In the following, the focus is on fieldbus protocols that are most widely used in industrial communication networks, and they are:

- FF H1 (Foundation Fieldbus High1)
- FF HSE (High Speed Ethernet)
- Profibus PA (Process Automation)
- ProfiNet
- Profibus DP (Decentralised Peripherals)
- Modbus
- HART (Highway Addressable Remote Transducer)

For the listed protocols in Table 1, technical characteristics are shown by layers.

Table 1. Technical characteristics of protocols by layers [7]

Fieldbus Protocols	PHYSICAL LAYER		DATA LINK LAYER	APPLICATION LAYER	
	Comm. speed	Maximum distance	Error detection	Standards	Data transfer
FF H1	31.25 kbs	1.9 km, 9.5 km	16-bit CRC	IEC 61158, ISA SP50, IEC 61804	AI, AO, DI, DO, PID, PD, CS, MIO
Profibus PA	31.25 kbs	1.9 km, 9.5 km	16-bit CRC	IEC 61158	AI, AO, DI, DO
FF HSE	100 Mbs, 1 Gbs	100 m	16-bit CRC	IEC 61158	Same as H1
ProfiNet	100 Mbs, 1 Gbs	100 m	16-bit CRC	IEC 61158	Same as DP
Modbus	9.6 kbs, 12 Mbs	1512 m	1-bit	IEC 61158	Registers
Profibus PA	9.6 kbs, 12 Mbs	1512 m	1-bit	IEC 61158	AI, AO, DI, DO
HART	100 Mbs, 1 Gbs	3 km	CRC	IEC 61158	Commands

3. WIRELESS COMMUNICATION PROTOCOLS IN THE PROCESS INDUSTRY

WMN (Wireless Mesh Network) and communication protocols are being actively explored to find new applications and possibilities of their use. Standardisation is very important for the commercial use of these networks and for interoperability among different network equipment manufacturers. New specifications for wireless networks are under development by various standardisation groups such as the IEEE (Institute of Electrical and Electronics Engineers), where the IEEE 802.11 group is working on standardisation of WLAN (Wireless Local Area Network) and the IEEE 802.15.4. group is working on standardisation of wireless networks that use the capabilities of Mesh networks [8, 9, 10, 11, 12].

The IEEE 802.15.4 standard defines the physical and MAC (Media Access Control) layer for the needs to implement low-speed wireless networks. One of the goals of developing the standard was to network a large number of sensors in industrial applications, using devices with significantly lower prices and less power consumption [13, 14].

Those devices are mainly battery-powered, where the low data transfer bit rate, low price and long battery life are the basic design requirements that need to be fulfilled. Based on the IEEE 802.15.4., several industrial protocols have been developed, and the WirelessHART protocol is commercially the most applicable [15].

3.1. WIRELESSHART

The WirelessHART protocol is compatible with existing HART devices and applications. It is cost-effective and has a rational approach to wireless communication, supporting the industrial demands for simple, reliable and secure wireless communication technology [16, 17].

The WirelessHART protocol is organised as an ISO/OSI 7 communication model that supports four OSI layers [18]:

- Physical Layer,
- Data Link Layer,
- Network Layer and
- Application Layer.

It meets the necessary communication requirements for compatible equipment to support, i.e. ensure interoperability, so that all types of wireless devices of other manufacturers can be replaced without disrupting network performance or system performance [19,20].

The WirelessHART protocol is controlled at a relatively low data transfer rate compared to the IEEE 802.11b standard for computer wireless networks and operates at a frequency of 2.4 GHz in the ISM (Industrial Scientific and Medical) radio band [21, 22]. The basic attributes of the WirelessHART protocol are shown in Table 2.

Table 2. WirelessHART protocol attributes

Attributes	Description
Wireless standard	IEEE 802.15.4-2006 250 kbps
Frequency	2.4 GHz
Distance	Up to 200 m on a directly visible pathway
Charging	Battery or solar power
Number of devices	No limit is defined
Based on industrial standard	HART – IEC 61158 EDDL – IEC 61804-3 Radio & MAC IEEE 802.15.4. (TM)-2006

4. OBJECTIVES

The main objective of introducing an integrated wired/wireless network model is the new architecture of communication networks in the process industry, which are accompanied by appropriate features, such as:

- Each network device, i.e. node, acts as a router.
- Almost all network devices are static.
- New radio technology, such as multi-channels, is used.
- Gateway is used to link devices in a network and enable communication among them.
- Network generally represents a combination of wireless and wired devices.
- WMN is a self-configuring and self-organising network.

These networks are considered to be one type of Ad-Hoc Networks where nodes are static, but they are also wireless sensor networks where nodes contain one or more sensors and act as routers [23, 24, 25].

Wireless technologies for most applications in the process industry offer a wide range of solutions that provide a higher return on investment, such as [26, 27]:

- **Remote applications**. When the devices used are kilometres away from the place of data usage, cabling is impractical. Wireless technology offers a more practical solution, for example, using wireless technology, existing communication networks can be utilized to transfer data from such remote devices.
- **Applications near facilities.** The devices for obtaining necessary data are not very far from the place of data usage, but there are obstacles, such as: rivers, highways, railways, etc., which can make cabling impractical. It is especially the case for hard-to-reach locations within facilities, e.g. tanks. Wireless technology can easily link tanks to a control room or any other location within the facility, so the process control function can be realized.
- **Applications within facilities**. Although communication distances within facilities are relatively small, wireless technology, i.e. wireless Mesh networks are often preferred due to the high cost of wiring devices. Since they are easy to install and expand, such wireless networks reduce the cost of adding new measuring devices.

5. SOFTWARE TOOLS

Emerson's I/O on Demand Calculator has been used to calculate labour costs, install devices, set up electrical installations, install cable guideways, etc. It provides flexibility with installed devices in a facility, containing the following options:

- wired device connection,
- Foundation Fieldbus,
- wireless device connection,
- Electronic Marshalling (an innovative solution for connecting devices within a facility to Emerson's DCS (Distributed Control System) DeltaV system).

Using the I/O on Demand Calculator, it is possible to determine the best type of device and the best installation method for each network integration situation. Some of the key calculation factors are:

- the average distance from devices to the control room,
- the percentage of devices that can be installed using the wireless technology and Electronic Marshalling

There are two distances as an analysis factor of integration costs:

- distance, i.e. cable length from the control room to the junction box, and
- distance from the junction box to the installed device in the facility.

A feasibility study for the introduction of an integrated wired/wireless communication network model was carried out on a real facility in a sugar refinery in Brčko in such a way that the results can be applied to other types of facilities by adjusting the installed devices and their average distance between a control room and junction boxes.

6. MODELS AND METHODS OF THE RESEARCH

The data required for the feasibility study for introducing an integrated wired/wireless communication network model in a sugar refinery in Brčko were obtained from the process maintenance service. As can be seen in Figure 3, a cabinet with the DCS DeltaV control system containing a controller and I/O cards [28] is located in the control room.

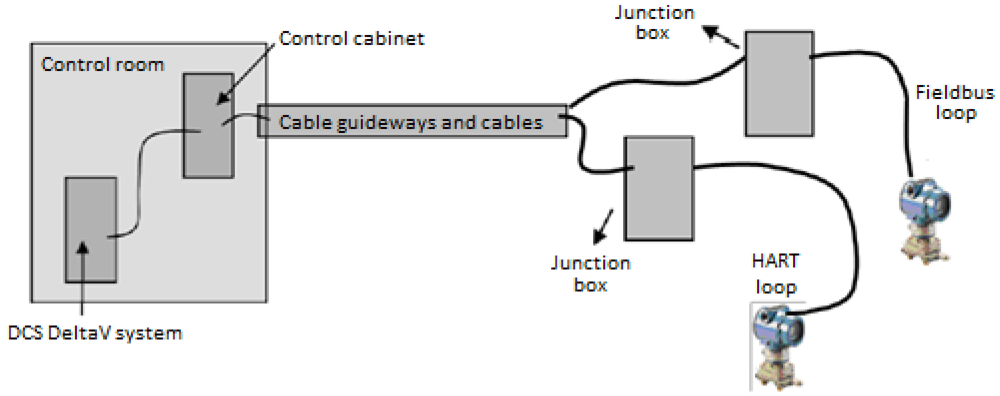

Figure 3. Wired devices in a sugar refinery [29]

In order to introduce an integrated wired/wireless communication network model as in Figure 4, it is necessary, according to the requirements of the process maintenance service at a sugar refinery in Brčko, to pass through the following scenarios [28]:

- Scenario 1: 75% of wired devices and 25% of Foundation Fieldbus
- Scenario 2: 33% of wired devices, 44% of Electronic Marshalling and 23% of Foundation Fieldbus
- Scenario 3: 26% of wired devices, 39% of Electronic Marshalling, 23% of Foundation Fieldbus and 12% of wireless devices.

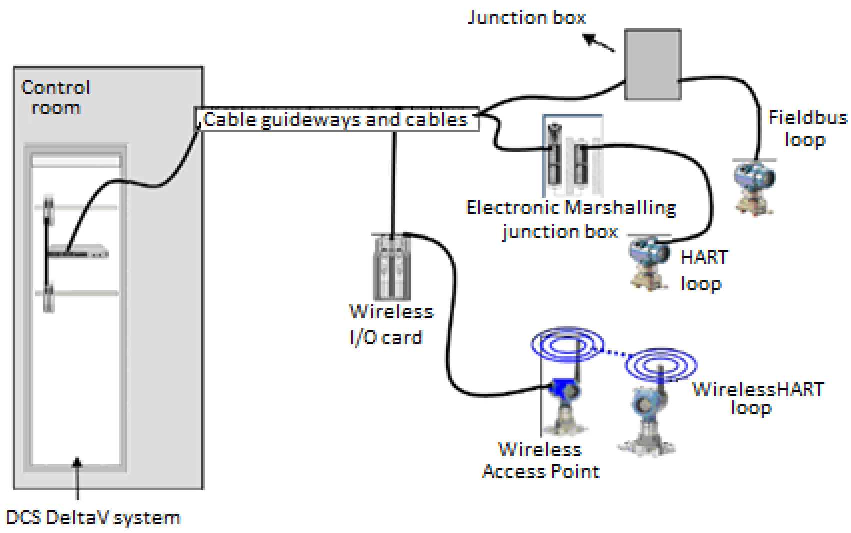

Figure 4. Model of an integrated wired/wireless communication network in a sugar refinery [29]

7. RESULTS OF THE RESEARCH

Each of these scenarios is calculated at distances of 30 metres, 60 metres, 90 metres, 120 metres, 150 metres and 180 metres from the control room to the junction box. In each scenario, the maximum wiring distance from the junction box to the device in the facility is about 10 meters, and for the Fieldbus loop is, on average, about 5 metres between the junction box and the sensor. The average cost of installation is $ 10 per metre [28].

A feasibility study for introducing an integrated wired/wireless communication network model starts from Scenario 1, where potentially 1500 out of a total of 2000 process measuring devices in a sugar refinery can be wired, which is 75%, and 500 devices can use Foundation Fieldbus, which is 25% (Table 3).

Table 3. Number of I/O devices for Scenario 1

	I/O							
Instrument Description	Wired Number of I/O	CHARMS Control Room Number of I/O	CHARMS Field Junction Box Number of I/O	IS CHARMS Control Room Number of I/O	IS CHARMS Field Junction Box Number of I/O	Fieldbus V11 Number of I/O	Fieldbus by Others Number of I/O	Wireless Number of I/O
Number of Field Instruments	400	400	400	400	400	400	400	400
AI	300	0	0	0	0	100	100	0
AO	300	0	0	0	0	100	100	0
DI	300	0	0	0	0	100	100	0
DO	300	0	0	0	0	100	100	0
RTD	300	0	0	0	0	100	100	0
Total No of I/O	1500	0	0	0	0	500	500	0

After entering the data into the I/O on Demand Calculator, the total cost for this scenario is $ 7634 and is shown in Table 4.

Table4. Costs for Scenario 1

	Cost $,000							
Summary	Traditional Wired	CHARMS Electronic Marshalling	CHARMS Field Junction Box	IS CHARMS Electronic Marshalling	IS CHARMS Field Junction Box	Fieldbus V11	Fieldbus by Others	Wireless
Installation Materials	$ 809	$ 50	$ 50	$ -	$ -	$ 364	$ 367	$ 150
Installation Costs (Labour Only)	$ 1.017	$ -	$ -	$ -	$ -	$ 161	$ 169	$ -
Terminations	$ 289	$ -	$ -	$ -	$ -	$ 36	$ 37	$ -
Quality, Configure and commission	$ 2.423	$ -	$ -	$ -	$ -	$ 801	$ 911	$ -
Total	$ 4.539	$ 50	$ 50	$ -	$ -	$ 1.362	$ 1.484	$ 150
Combined System Total	$ 7.634							
Savings In Cost $,000	Base	$0	$0	$0	$0	$3.177	$3.055	$0
% Savings in Cost	Base	0,00%	0,00%	0,00%	0,00%	70,00%	67,31%	0,00%
	Wired	CHARMS Electronic Marshalling	CHARMS Field Junction Box	IS CHARMS Electronic Marshalling	IS CHARMS Electronic Marshalling	Fieldbus V11	Fieldbus by Others	Wireless
Cost per point ($)	$ 2.751	$ -	$ -	$ -	$ -	$ 2.476	$ 2.697	$ -

In Scenario 2, where out of a total of 2000 process measuring devices, 660 can be wired, which is 33%, 880 can use Electronic Marshalling, which is 44%, and 460 can use Foundation Fieldbus, which is 23% (Table 5).

Table 5. Number of I/O devices for Scenario 2

I/O								
Instrument Description	Wired Number of I/O	CHARMS Control Room Number of I/O	CHARMS Field Junction Box Number of I/O	IS CHARMS Control Room Number of I/O	IS CHARMS Field Junction Box Number of I/O	Fieldbus V11 Number of I/O	Fieldbus by Others Number of I/O	Wireless Number of I/O
Number of Field Instruments	400	400	400	400	400	400	400	400
AI	132	0	176	0	0	92	92	0
AO	132	0	176	0	0	92	92	0
DI	132	0	176	0	0	92	92	0
DO	132	0	176	0	0	92	92	0
RTD	132	0	176	0	0	92	92	0
Total No of I/O	660	0	880	0	0	460	460	0

After entering the data into the I/O on Demand Calculator, the total cost for this scenario is $ 6742 and is shown in Table 6.

Table 6. Costs for Scenario 2

Cost $,000								
Summary	Traditional Wired	CHARMS Electronic Marshalling	CHARMS Field Junction Box	IS CHARMS Electronic Marshalling	IS CHARMS Field Junction Box	Fieldbus V11	Fieldbus by Others	Wireless
Installation Materials	$ 394	$ 50	$ 592	$ -	$ -	$ 335	$ 338	$ 150
Installation Costs (Labour Only)	$ 452	$ -	$ 471	$ -	$ -	$ 149	$ 156	$ -
Terminations	$ 127	$ -	$ 111	$ -	$ -	$ 33	$ 34	$ -
Quality, Configure and commission	$ 1.066	$ -	$ 708	$ -	$ -	$ 737	$ 838	$ -
Total	$ 2.039	$ 50	$ 1.881	$ -	$ -	$ 1.254	$ 1.367	$ 150
Combined System Total	$ 6.742							
Savings In Cost $,000	Base	$0	$1.989	$0	$0	$785	$672	$0
% Savings in Cost	Base	0,00%	97,55%	0,00%	0,00%	38,50%	32,97%	0,00%
	Wired	CHARMS Electronic Marshalling	CHARMS Field Junction Box	IS CHARMS Electronic Marshalling	IS CHARMS Electronic Marshalling	Fieldbus V11	Fieldbus by Others	Wireless
Cost per point ($)	$ 2.809	$ -	$ 52	$ -	$ -	$ 2.479	$ 2.701	$ -

In Scenario 3, where out of a total of 2000 process measuring devices in a sugar refinery, 520 can potentially be wired, which is 26%, 780 can use Electronic Marshalling, which is 39%, 460 can use Foundation Fieldbus, which is 23%, and 240 devices are used for 8 wireless networks, which is 12% (Table 7).

Table 7. Number of I/O devices for Scenario 3

	I/O								
Instrument Description	Wired Number of I/O	CHARMS Control Room Number of I/O	CHARMS Field Junction Box Number of I/O	IS CHARMS Control Room Number of I/O	IS CHARMS Field Junction Box Number of I/O	Fieldbus V11 Number of I/O	Fieldbus by Others Number of I/O	Wireless Number of I/O	
Number of Field Instruments	400	400	400	400	400	400	400	400	
AI	104	0	156	0	0	92	92	48	
AO	104	0	156	0	0	92	92	48	
DI	104	0	156	0	0	92	92	48	
DO	104	0	156	0	0	92	92	48	
RTD	104	0	156	0	0	92	92	48	WIOC Systems
Total No of I/O	520	0	780	0	0	460	460	240	8

After entering the data into the I/O on Demand Calculator, the total cost for this scenario is $ 6374 and is shown in Table 8.

Table 8. Costs for Scenario 3

	Cost $,000							
Summary	Traditional Wired	CHARMS Electronic Marshalling	CHARMS Field Junction Box	IS CHARMS Electronic Marshalling	IS CHARMS Field Junction Box	Fieldbus V11	Fieldbus by Others	Wireless
Installation Materials	$ 327	$ 50	$ 536	$ -	$ -	$ 335	$ 338	$ 261
Installation Costs (Labour Only)	$ 355	$ -	$ 415	$ -	$ -	$ 149	$ 156	$ 78
Terminations	$ 100	$ -	$ 98	$ -	$ -	$ 33	$ 34	$ 1
Quality, Configure and commission	$ 840	$ -	$ 627	$ -	$ -	$ 737	$ 838	$ 65
Total	$ 1.622	$ 50	$ 1.677	$ -	$ -	$ 1.254	$ 1.367	$ 404
Combined System Total	$ 6.374							
Savings In Cost $,000	Base	$0	$1.572	$0	$0	$368	$255	$1.217
% Savings in Cost	Base	0,00%	96,92%	0,00%	0,00%	22,67%	15,72%	75,06%
	Wired	CHARMS Electronic Marshalling	CHARMS Field Junction Box	IS CHARMS Electronic Marshalling	IS CHARMS Electronic Marshalling	Fieldbus V11	Fieldbus by Others	Wireless
Cost per point ($)	$ 2.835	$ -	$ 58	$ -	$ -	$ 2.479	$ 2.701	$ 44.944

Analysing the costs obtained by the I/O on Demand Calculator for each scenario, the following results of the cost dependence on the distances are gained, as shown in Figure 6. The costs increase linearly at a rate of $ 6.42 per metre for Scenario 1, at a rate of $ 3.88 per metre for Scenario 2, and at a rate of $ 3.28 per metre for Scenario 3.

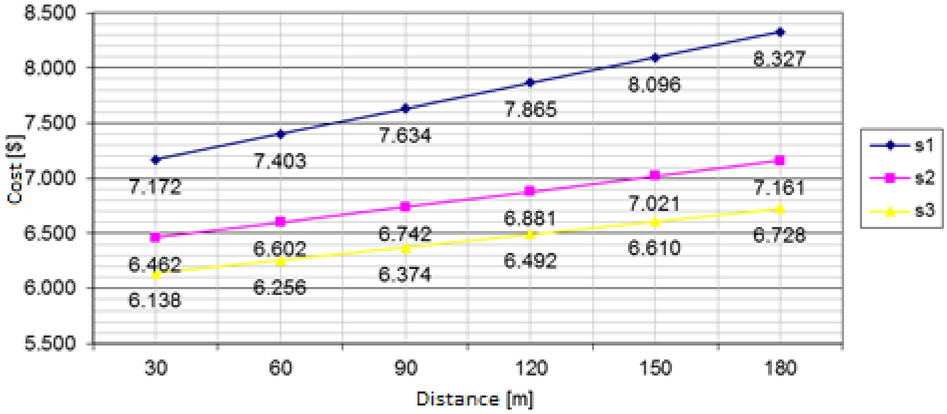

Figure 6. Analysis of the costs in dependence on the distance

The obtained diagrams in Figure 6 show that an integrated wired/wireless network model in industrial process control applications is cost-effective in each scenario, both over long distances and in applications where distances are relatively short. The total costs for the feasibility study for introducing an integrated wired/wireless communication network on a real facility at a sugar refinery in Brčko are shown in Table 9.

Table 9. Total costs of all scenarios

	Scenario 1	Scenario 2	Scenario 3
Costs ($m)	6.42	3.88	3.28
Installation savings ($m)		2.54	3.14
Savings (%)		39.56	48.9
Total number of devices	2000	2000	2000
Wired network	1500	660	520
Electronic Marshalling		880	780
Foundation Fieldbus	500	460	460
Wireless network			240

At the end of this study, by analysing the results presented in Table 9, we can conclude that there is a justification for introducing an integrated wired/wireless communication network at the sugar refinery in Brčko. The results show savings between 39.56% and 48.9%, i.e. those potential savings of 48.9% are achieved using Scenario 3 where 26% of devices are wired, 39% of devices use Electronic Marshalling, 23% of devices use Foundation Fieldbus and 12% of devices are connected wirelessly.

8. CONCLUSION

In order to obtain a satisfactory industrial communication network based on the results presented in this paper, we can conclude that there is a justification for introducing a model of an integrated wired/wireless communication network in a real facility at a sugar refinery in Brčko. The application of the latest integrated wired/wireless communication networking technology is a highly reliable and efficient industrial solution and represents a great opportunity for industrial production to rise to a higher level of reliability and performance. Integrated wired/wireless solutions in industrial communication networks provide access to important information from parts of manufacturing facilities that have not been available before and provide the possibility to add new measurement points where access was previously too expensive and inaccessible.

In general, the study results show that the presence of a wireless network in the integration is cost-effective and contributes positively with additional savings at any distance and much more at great distances, which is of great importance for engineering in terms of Building Environment and Architecture.

9. REFERENCES

[1] Felser M.: „The Fieldbus Standards: History and Structures", Technology Leadership Day, 2002, Organised by Microswiss Network, HTA Luzern, Oktober 2002.
[2] Pablo Soldati, Haibo Zhang, Mikael Johansson: „Deadline-constrained transmission scheduling and data evacuation in WirelessHART networks", Technical Report, Royal Institute of Technology (KTH), Stockholm, Sweden, September 2008.
[3] Website http://www.hartcomm.org, HART Communication Foundation, dostupno dana 10. 2. 2020.
[4] Website http://www.howlingpixel.com/i-en/Fieldbus, dostupno dana 19.11.2019.
[5] Website www.fieldbus.org, Foundation Fieldbus, dostupno dana 10. 2. 2020.
[6] L. Krishnamurthy, R. Adler, P. Buonadonna, J. Chhabra, M. Flanigan, N. Kushalnagar, L. Nachman, M. Yarvis: „Design and deployment of industrial sensor networks: experiences from a semiconductor plant and the north sea", SenSys'05, San Diego, California, USA, November 2–4. 2005. pp. 64–75.
[7] Website http://www.pdhonline.com/courses/e448/e448content.pdf, dostupno dana 20.11.2019.
[8] A.S. Tanenbaum: „Computer Networks", Fourth Edition, ISBN: 978-0130661029, Prentice Hall, Boston, 2003.
[9] J Song, A Mok, D Chen, M Nixon: „Challenges of Wireless Control in Process Industry", Proceedings of Workshop on Research Directions for Security and Networking in Critical Real-Time and Embedded Systems, San Jose, California, USA, April 4. 2006.
[10] A. Willig, K. Matheus, A. Wolisz: „Wireless Technology in Industrial Networks," Proceedings of the IEEE, Vol. 93, Jun. 2005.
[11] Website www.ieee802.org/15/pub/TG4.html, IEEE 802.15.4 WPAN Task Group, dostupno dana 10. 2. 2020.
[12] Website http://standards.ieee.org/wireless, IEEE wireless standards, dostupno dana 10. 2. 2020.
[13] Website www.wi-fi.org, Wi-Fi Alliance, dostupno dana 10. 2. 2020.
[14] Website www.wina.org, Wireless Industrial Networking Alliance (WINA), dostupno dana 10. 2. 2020.

[15] M. Kostadinović, Z. Bundalo, D. Bundalo, P. Gojkovic: “CONFIGURATION OF SMART DEVICES IN WIRELESSHART NETWORKS”, 14th International Research/Expert Conference”Trends in the Development of Machinery and Associated Technology” TMT 2010, Mediterranean Cruise, 11-18 September 2010.

[16] M. Kostadinović, M. Stojčev, Z. Bundalo, D. Bundalo: „Upravljanje WirelessHART mrežom”, Međunarodni naučno-stručni simpozijum INFOTEH-JAHORINA 2009, Jahorina, 18-20. 03. 2009. Vol. 8, Ref. A-16, p. 71-75.

[17] M. Kostadinović, B. Popović, N. Popović: „Dizajn i implementacija mrežnih uređaja koji koriste WirelessHART protokol”, Međunarodni naučno-stručni simpozijum INFOTEH-JAHORINA 2010, Jahorina, 17.-19. 03. 2010. Vol. 9, Ref. A-26, p. 123-127.

[18] Yipeng Wang-Implementation of the WirelessHART MAC Layer in the OPNET Simulator

[19] Deji Chen, Mark Nixon, Aloysius Mok: „WirelessHART: Real-Time Mesh Network for Industrial Automation”, ISBN: 978-1-4419-6046-7, Springer, New York, 2010.

[20] X. Zhu, P.-C. Huang, S. Han, A. K. Mok, D. Chen, M. Nixon: „RoamingHART: A Collaborative Localization System on WirelessHART“, Real-Time and Embedded Technology and Applications Symposium (RTAS), 2012 IEEE 18th, Beijing, China, April 2012. pp. 241 – 250.

[21] Dan Henriksson: „Resource-Constrained Embedded Control and Computing Systems”, Department of Automatic Control, Lund University, Sweden, 2006.

[22] Website http://www.awiatech.com, Awiatech, dostupno dana 10. 2. 2020.

[23] Caro D: „Wireless Network for Industrial Automation”, Second Edition, The Instrumentation, Systems and Automation Society - ISA Press, North Carolina City, 2005.

[24] J. R. Gisbert, C. Palau, M. Uriarte, G. Prieto, J. A. Palazón, M. Esteve, O. López, J. Correas, M. C. Lucas-Estañ, P. Giménez, A. Moyano, L. Collantes, J. Gozálvez, B. Molina, O. Lázaro, A. González: „Integrated system for control and monitoring industrial wireless networks for labor risk prevention”, Elsevier Journal of Network and Computer Applications, Volume 39, March 2014. Pages 233–252, Impact Factor 1.467.

[25] HART Communication Foundation: „Control with WirelessHART”, HCF LIT-127, Revision 1.0, June 30. 2008.

[26] S. Raza: „Secure Communication in WirelessHART and its Integration with Legacy HART“, Technical Report, Swedish Institute of Computer Science, Networked Embedded Systems (NES) Lab, Sweden, January 13. 2010.

[27] Silva Ivanovitch, Luiz Affonso Guedes, Paulo Portugal, Francisco Vasques: „Reliability and Availability Evaluation of Wireless Sensor Networks for Industrial Applications“, Journal Sensors 2012, Vol. 12, January 2012. pp. 806-838, Impact Factor: 1.953.

[28] M. Kostadinović, Z. Bundalo, D. Bundalo, A. Stjepanović: “ Feasibility Analysis for Introducing of Integrated Wired/Wireless Industrial Communication Networks”, 17th International Research/Expert Conference”Trends in the Development of Machinery and Associated Technology” TMT 2013, Istanbul, Turkey, 10-11 September 2013, pp. 377-380.

[29] Emerson Process Management, “I/O on Demand Cost Study”, DeltaV Whitepaper, February 2011.