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Optimal Management Network Topology in a CIMM System The General Case

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Abstract: CIMMs (Computer Integrated Manufacturing systems) are important systems for overall automation of manufacturing enterprises, especially big ones. The general issues of the computer system topology were analyzed earlier. The present case study concerns the detailed design of the optimum LAN for the CIMMs sphere, based on the actual data for a big Polish household appliance manufacturer. For the data, the optimal LAN topology is determined, assuming development of democratic networks. In addition, the optimal topology for the general case is derived.

Keywords: Factory automation, manufacturing, management.

1. INTRODUCTION

When designing a CIMM system, the designer should think about the communication network topology, determining it on some actual and not virtual considerations. In order that the designing process is understandable and teaching, it seems worthwhile to start from an actual case study and proceed to the more complex cases. This approach has been assumed for this paper. The initial data are taken from the example of Polar, the former biggest household manufacturer (the Enterprise) in Poland (the Country).

The article presents the notion of CIMMs Franasik et al. (2001), some basic information about the general topologies of CIMMs [2-5]Izworski et al. (2003b, c), Lewoc et al. (2006a), Lewoc et al (2009), determined on the basis of robustness evaluation (μ-function), a proposal of the optimal network topology assuming democratic character of the network, proven for the initial network data. Some hypotheses for more general networks are also given.

2. SOME INTRODUCTION TO CIMMs

1.1 Initial Information

The notion of CIMMs (Computer Integrated Manufacturing and Management system) was introduced for the first time in Franasik et al. (2001), Lewoc et al. (2006a). Such systems are severely needed in actual enterprises, especially in big factories involved in manufacturing. In spite of that high demand for CIMMs, ICT people can not present any good offer; the ICT technology providers specialized in management can not and do not wish to be involved in the Manufacturing problems and those specialized in Manufacturing can not and do not wish to cope with management issues.

Intensively advertised work on standards for development of standards for management and manufacturing systems seem to base on rather naïve assumption that good standards on some novel solutions may be obtained without educating people of detailed knowledge in all areas covered by the overall system.

Considering it, a team of ICT and automation designers commenced initial design and research work oriented towards development a reasonable process for design and development of CIMMs. This work included some approach to optimization of the communication network topology Izworski et al. (2003b, c), Lewoc et al (2009), and performance evaluation/prediction of a ctual computer networks Izworski et al. (2003a), Izworski et al. (2004), Lewoc et al. (2006b), Lewoc et al. (2007), Lewoc et al. (2010a, b, c).

2.2. General Approach to CIMMs Design

The general approach ti CIMMs design is described e.g. in Izworski (2007). The general structure of any CIMM system could be planned only in a very general way at present. Therefore, it is not reasonable to design a solution for all possible CIMM problems at the very beginning of the design work.

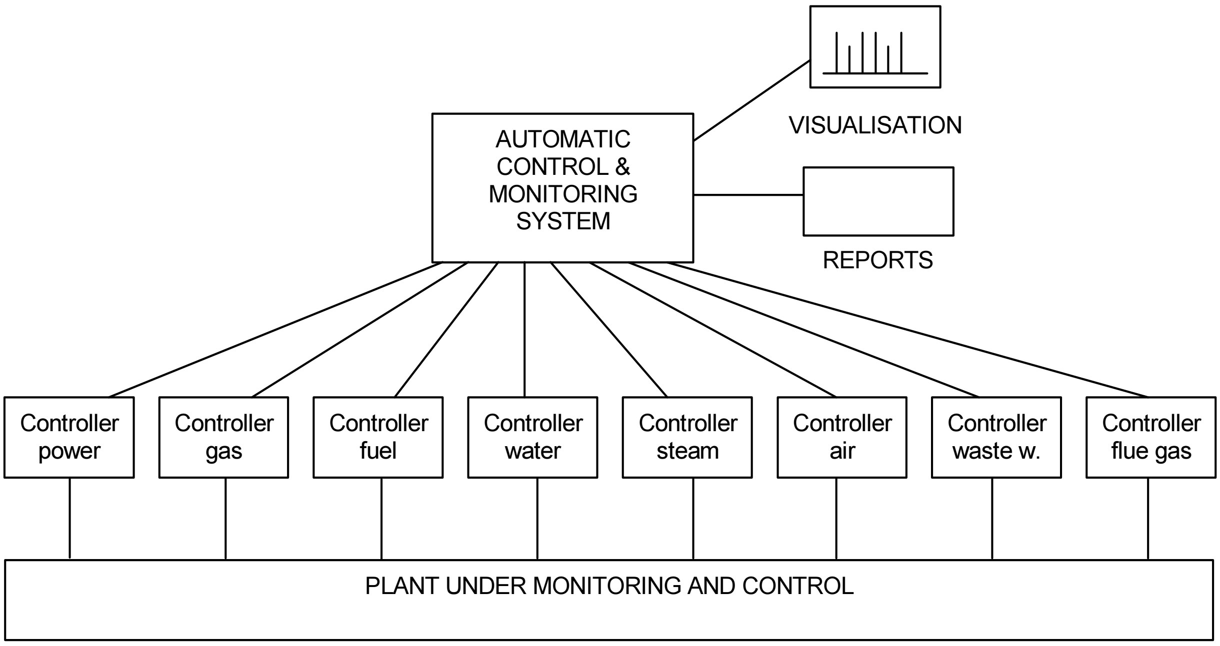

Fig. 1. General structure of System Media.

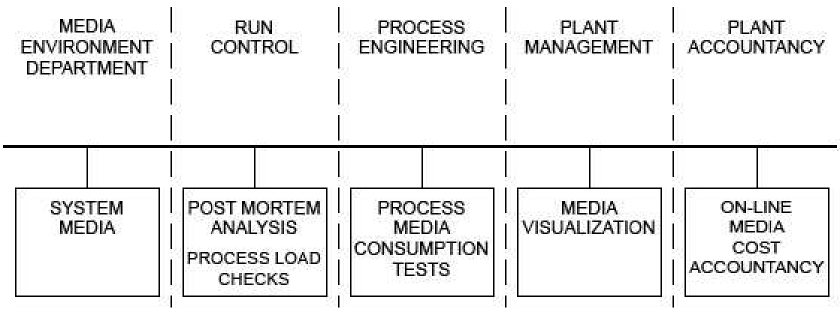

Fig. 2. The first thread through CIMMs.

Thus, the first thread in the CIMM system, i.e. the minimum set of tasks needed for development a interconnection of the CIMMGs and CIMMTs useful and profitable for the enterprise involved, should be defined, feasible to be designed, worked out and implemented by a finite team. Basing on these experience and standards worked out, it should be possible to design and implement further CIMM threads. The first thread in the CIMMs will be called the System Media and its architecture is presented in Fig. 1.

The most attractive functionality of the managerial part of CIMMS in the first thread seems to be the Accountancy Department calculating the working media costs per a single product or a small production lot as presented in Fig. 2. There is no revolution needed to organize it; the only what is needed is to develop settling programs for working medium consumption for the System Media of Fig. 1 and to charge individual users with the working media costs in e.g. minutely and not monthly cycles.

The present paper is devoted to devising some optimum topology for the communication network for the management part of CIMMs.

3. OPTIMAL TOPOLOGY OF THE MANAGEMENT CIMMs COMMUNICATION NETWORK

3.1. Enterprise Description

The managerial component of the Enterprise (the Component) needed some three hundred people to prepare the production and management processes and to sell the products (various types of freezer, refrigerators, washing machines, dish washers, etc.). The Component was organized into several levels of hierarchy where any entity has to be provided with a possibility of direct contacting with their superior (transmission of reports, reception of commands) entities, subordinate ones (transmission of commands, reception of reports) and with the cooperating entities on the same hierarchy levels.

For such general organization, we will try to propose an optimum LAN communication network.

3.2. Basic Requirements for the Communication Network

The Team, basing on the biggest experience available in the Country (Han et al. (2008), Lewoc et al. (2008), Lewoc et al. (2011a, b)), formulated and adopted a good design practice as follows:

To achieve implementation and operation success of any large scale LAN communication network, its topology should be (in an ideal case) an isomorphic image of the network interconnecting human beings and technical equipment.

This rule is used, often, for the software topology; the Team think that it should be used to the hardware topology since such isomorphism is very much beneficial for the rather complex processes of communication network design implementation and operation.

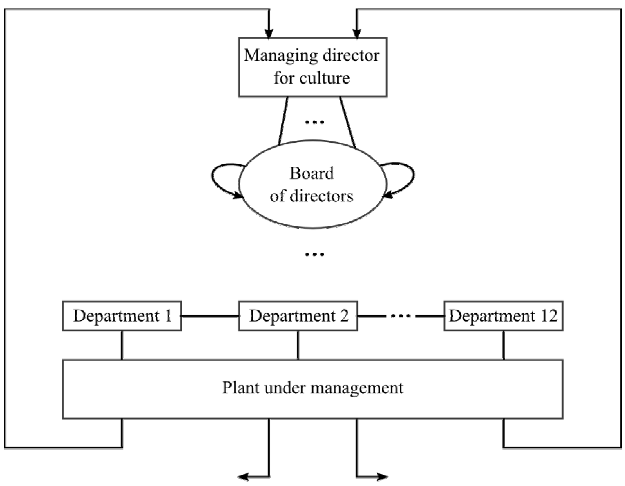

Fig. 3. General Organization of the Managerial Component of the Enterprise.

The enterprise coped with in the present paper is Polar, Wrocław (the Enterprise), the former biggest household appliance manufacturer in the country. The general organization of the management component of the Enterprise is shown in Fig. 3.

The other common-sense requirement is that the Network should be democratic. This implies that the ICT equipment is identical for each user and that the optimization should be based on maximization of the quality of service for the worst served User.

Another non-trivial requirement for the Network is that it should be optimized from the point of view of robustness. That's true: in the present time of HiTech, earlier reliability based criteria are not enough; in present days the designer must do its best to ensure adequate resistance to disturbance. i.e. the robustness. Some work has been done concerning comparison of the basic two network topologies: the common medium topology and the star one. To facilitate understanding of the present article, some citation of the works will be presented below.

3.2.1. Optimization of Network Topology basing on the Basic Robustness Measure (μ Function)

The problems were discussed elsewhere (Izworski et al. (2003b, c), Lewoc et al (2009)).

3.3. General Topology of the Network

The general topology of the Network can be, therefore, depicted as in Fig. 4.

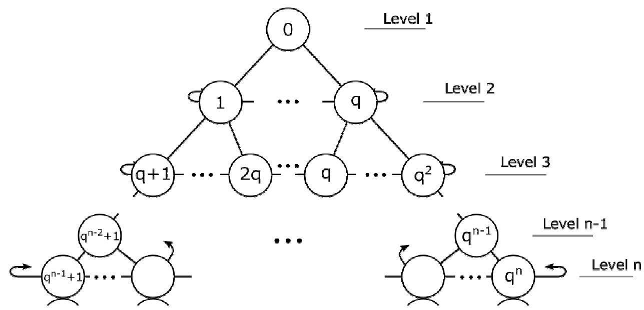

Fig. 4. General Topology of the Network.

It may be noticed that the proposed numbers of the network nodes (switches) along the extreme RH branch meet the assumptions of the geometric series of the integer quotient q and the first term a1 and the numbers of nodes from the level *1* to *n* are equal to the partial sum of the geometric series, i.e.:

$$S_n = \frac{1-q^n}{1-q} \quad . \tag{1}$$

Individual branches in this network represent network links (hops) and, on the basis of the earlier discussion, are the same, so – without any worsening of the generality, are assumed to be equal 1. For the optimization, we have to determine q minimizing the optimality criterion defined hereinafter.

3.4. The Optimization Criterion

The objective of any democratic network should be that any User (k-th, k = 1,…, q^n) of the network obtains the same service quality as any other User within the same class (on the same level in this case). Considering the fact that the network is homogeneous in normal operating conditions, this means that the objective function should be the biggest distance from the k-th to any other user (node) in the network in normal operation (i.e. via horizontal links).

Note that we have to consider only the standard connections (closed loops) in the Network; any emergency connections are used in abnormal (emergency) network conditions; in this case the designer must consider quite other criteria, e.g. the minimum time to restore the normal conditions.

Note that, also, the topology should be extended to the complete form shown in Fig. 4; incomplete network (missed nodes on the n-th level imply, obviously, non democratic distribution of work of the users on the (n-1) level).

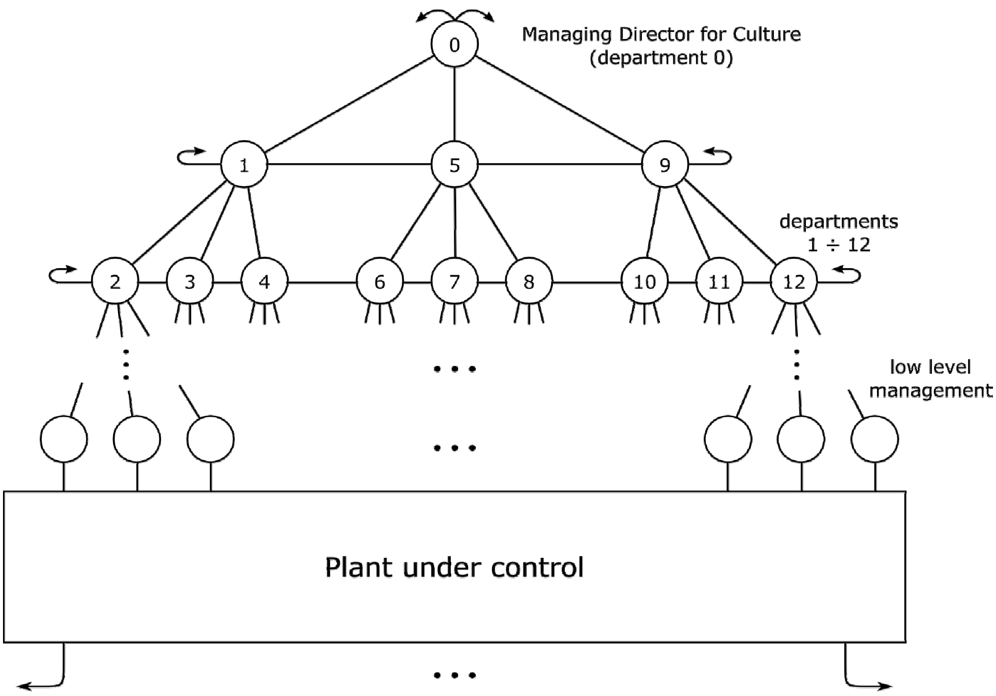

Fig. 5. Optimal network for the case study.

3.5. Optimal Topology for the Case Study Network

Determination of the optimum network for the case study is equivalent with finding the quotient q for which, for the minimum level number $n(q)$ such that the number of nodes of the network, i.e. the partial sum of the geometric series:

$$n = n(n,q) = \frac{1-q^{n(q)}}{1-q} \geq 300 \ , \tag{2}$$

the maximum number of links (hops) between the nodes $q^{n(q)\ -1}+1$ and q^n , $d(q)$, is the lowest value what is equivalent to that $q^{n(q)-1}(q-1)$ is of the lowest value. For the case study, it can be simply verified directly.

Let us note that we may to limit our investigations to $2 < q < 300$. Indeed, for q = 1, we have the case of a common media network, disqualified by the robustness investigation results.

On the other hand, for $q > 300$, we have $n(q) = 1$, so the number of links (hops), $d(q)$, mentioned above equals q and, obviously:

$$\prod_{q>300} d(q+1) > d(q) \ . \tag{3}$$

For $2 < q < 300$, the values of $n(q)$ and $d(q)$ were verified by direct calculations; $d(q)$ assumes the minimum value for $q = 3$.

Thus, considering the democratic criterion and the number of network nodes/switches needed, the optimal communication network for the case study will be that shown in Fig. 5.

The above case study was presented by Lewoc (2012).The general case is considered in the next Section 5.

5. THE GENERAL CASE

From (2) and (3), we have:

$$d(q,n) = q^{n-1}(q-1) = (N \cdot (q-1)+1)(q-1) \quad (4)$$

Thesis:

$$\prod_{\substack{N=1,\dots \\ q=2,4,5,6,\dots}} d(N,q) > d(3,q) \ . \quad (5)$$

The thesis will be proved by induction with respect to $N>=4$:

Assumption:

Let (5) is fulfilled for some $N>=4$.

We have

$$\begin{aligned}&(N(q-1)+1)(q-1) > (N(2)+1)2 = \\ &(2N+1) = 2(2N+1) = 4N+2\end{aligned} \ . \quad (6)$$

Then:

$$\begin{aligned}&d(3, N+1) = ((N+1)(3-1)+1)2 = \\ &2(N+1)2+1 = 4N+6\end{aligned} \quad (7)$$

and

$$\begin{aligned}&d(q, N+1) = ((N+1)(q-1)+1)(q-1) = \\ &(N(q-1)+1)(q-1) + (q-1)^2 \geq 2(2N+1) + \\ &(q-1)^2 = 4N+11 > 4N+6 = d(3, N+1)\end{aligned} \quad (8)$$

Qed.

We have also to consider the case of $q=2$

$$\begin{aligned}&d(N,2) = N+1 = \\ &and \\ &d(2, N+1) = ((N+1)+1)(1) = N+1\end{aligned} \ . \quad (9)$$

Qed.

5. CONCLUSIONS

Assuming the democratic criterion defined in the present paper, the three-partie communication network is the optimal one for the case study of 300 network nodes / switches, i.e. network users as well as for the general case.

A hypothesis has been defined that the same holds true for any network of limited size (finite n), observing the democratic criterion in the understanding of the present paper.

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