Abstract—This paper analyzes the applicability of two economy competition models (namely, Cournot and Bertrand) to analyze smart factory automation systems. The manufacturing setting considered includes players from both the Manufacturing Execution Systems (MES) layer – machines and transportation devices – and the Enterprise Resource Planning (ERP) layer – energy providers and lighting systems. All actors act both as providers and requestors of energy relevant services. An answer is attempted to several questions raised in the presented context (What is price/cost? What are the services provided / requested? Who are the price setters? Who makes profit in the discussed setting?). Many other questions remain open for further research. The intention is to provide initial guidelines for simulation / implementation of the proposed approach in a real factory automation setting.

1. INTRODUCTION

In March 2007, the European Council has set ambitious energy and climate change objectives for 2020 [1]: to reduce greenhouse gas emissions by 20%, to increase the share of renewable energy to 20% and to make a 20% improvement in energy efficiency. The goals set forth are a challenge, but also a business opportunity. Factories are the significant players that will drive the technological base improvement of EU manufacturing across a broad range of sectors.

To reinforce industrial competitiveness by making industry more efficient, quick adaptation to business trends imposed by fluctuations in energy prices is a must. The introducing of energy consumption as a parameter to support the decision making process may help to forecast situations in which total losses incurred by having a production output below the maximum throughput are outweighed by energy savings.

The focus is shifting towards producing more products with less material, less energy and less waste. To achieve this, it is needed to not only analyze development and integration of enabling technologies and advanced materials, but also to investigate and apply at factory floor modeling paradigms from other domains. Specifically, this paper investigates how price/quantity based competition models traditionally analyzed in the field of economics could be applied in practice for studying energy efficient factory automation systems.

The paper is organized as follows: Section II introduces the factory automation systems of interest in this work, and discusses briefly Cournot and Bertrand competition models. Section III discusses the applicability of these models to energy efficient manufacturing systems from a general viewpoint. The authors do not claim to have found the answer to all presented issues. On the contrary, the intention is to present several research questions and attempts to correlate concepts in economy with corresponding implementation possibilities in the presented application domain. In this context, the testbed, the scenarios and the implementation plan to investigate the feasibility of one model over the other are presented. Section IV outlines the conclusions and discusses future work.

2. BACKGROUND

Modern ICT systems are decentralized, pervasive and very dynamic. It has been advocated [1][3] that to support the self adaptability and evolvability that are so much desired in such systems, interaction patterns between system components must be fluid [4] i.e. they should exhibit self-organizations based on the current needs, component status and context/environment.

The transformable, networked and learning factory of the future [5] is part of an open, loosely coupled, demand-driven environment where proactive agents/species are both competing and collaborating to achieve own benefit/profit.

Figure 1 illustrates the typical factory automation system of interest here.

The line is physically located at the premises of the Factory Automation Systems and technology Laboratory, Tampere University of Technology. It consists of 12 manufacturing cells, each containing at minimum one robot and a conveyor system. The layout of the cells is shown in Figure 2 (Cell 7 is a buffer). The line is capable of drawing layouts of mobile phones, using different combinations of frame/keyboard/screen types. The line incorporates smart lighting (with on/off/dimming options depending on the area
considered and its current working status). The energy consumed comes from both various energy providers and from own sources (e.g. solar panels installed on top of the building in which the factory automation system resides).

At Manufacturing Execution System (MES) level, the main concern is to fabricate the required products using minimum waste in terms of time, cost and energy consumption. Orders come from the higher level Enterprise Resource Planning (ERP) system. Indications on which energy provider should be utilized/ which machine should be utilized for processing a specific request/which route should be taken by a particular pallet to reach its final destination/which area of the line should be illuminated more / etc. make use of information at both MES and ERP level.

The problem of modeling ecosystems similar to this one, /their individuals/the space in which the individuals reside and their laws was approached in various ways [4]. Physical metaphors view individuals as computational particles, therefore limiting the number of behaviors possible to enforce. Chemical metaphors equate species to sorts of computational atoms and molecules living in localized solutions, therefore making it difficult to address e.g. spatial distribution. Biological metaphors see individuals as organisms with simple reactive behavior. Trophical metaphors revolve around the question of ‘who needs to eat who?’.

Market-based metaphors focus on the central issue of who needs to buy what from who. Competition in such models is generally either based on price or based on quantity (Table I). In Bertrand-type competition, sellers set prices and customers/buyers choose quantities at the prices set by the sellers. Firms produce whatever quantities are needed of the product, at the price that was set beforehand. Tough competition results in prices coming down as low as marginal cost (below which firms will never go because they will not make profit anymore). With the Bertrand model, it is possible to achieve perfect competition (firms out-pricing each other up to the point that both of them have zero profits) with 2 firms only. The way to avoid that is to ensure products are differentiated (i.e. that providers offer services that are different enough that prices charged can be a little higher than competitors”).

Cournot-type competition describes a situation when companies compete on the amount of output they will produce. The model was applied at ERP level for representing e.g. the strategic bidding problem for generation companies (GENCOs) [6], in the electricity industry for analyzing imperfect competition and market power issues [7]. Each firm chooses the quantity to produce such that holding all other firms’ quantities constant, they are maximizing profits (i.e. everybody is satisfied with what they are producing, given what everybody else is producing). The existence of a Cournot equilibrium can be determined by computing the residual demand for each firm (i.e. the demand for a firm, given the quantity absorbed by the other firms in the market) and the corresponding marginal revenue function (a function of other firms quantities). The price is determined by the market.

The question of which model to use when is best addressed by a rule of thumb related to how easy it is to produce the products. Quantity competition is more likely when there are lags in the production process (i.e. the firms just cannot produce more than a certain amount of items). Price competition is more likely when product comparison and manufacturing is easier.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>COURNOT AND BERTRAND COMPETITION MODELS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Goal</strong></td>
<td>Maximization of profit: Profit = Price x Quantity – Cost(Quantity)</td>
</tr>
<tr>
<td>Product Differentiation</td>
<td>no</td>
</tr>
<tr>
<td>Cooperation</td>
<td>no</td>
</tr>
<tr>
<td>Firms compete in</td>
<td>Quantity</td>
</tr>
<tr>
<td>Price</td>
<td>Price = Price (Quantity) Set such that supply = demand</td>
</tr>
<tr>
<td>Quantity</td>
<td>Set by firm (producers decide how much they wish to produce) Set simultaneously (before observing the quantity set by rivals)</td>
</tr>
<tr>
<td>Product</td>
<td>homogeneous</td>
</tr>
<tr>
<td>Better model in case</td>
<td>Capacity and Output difficult to adjust</td>
</tr>
<tr>
<td>Ignores</td>
<td>Capacity constraints (i.e. assumes firms satisfy all the demand) Search cost of consumers Diversity of products Dynamic competition (assumes the pricing game is a one shot game)</td>
</tr>
<tr>
<td>Demand</td>
<td>Buy everything from the lowest price</td>
</tr>
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</table>
3. COMPETITION MODELS FOR ENERGY EFFICIENT FACTORY AUTOMATION SYSTEMS

The above discussed competition models are applicable in factory automation scenarios, provided the main players are identified. The questions addressed are:
- Who are the providers of services?
- Who are the requestors of services?
- What are the services provided and requested?
- What is profit in the defined context?
- Who benefits from making profit?
- What is the currency used for trade? The currency should be something valued by all players.
- How is currency used up by the providers/requestors?
- Can the entities work for the currency, so that the amount of ‘currency savings’ increases on-the-fly? (Can they get a “salary”?)
- How much capital should have requestors/providers initially? (What is the “startup fund”?)
- How is price defined in the discussed context?
- Which entities are setting prices?
- What are the factors that influence prices?
- How is cost defined in the discussed context?
- Which entities are supporting costs?
- What are the factors that influence costs?

Figure 1 illustrates the considered factory automation setting.

Figure 3 Energy efficient Factory Automation Systems. Services provided and requested.

The players involved include MES-level entities (processing workstations, pallets, etc.), ERP level entities (here, in charge with smart lighting and energy provisioning), and the entities at the boundary between MES and ERP, with yet unclear positioning (here, e.g. the Energy Advisor). All entities in the line have something to offer at a price (the quantity of payment/compensation given by one party to another in return for goods or services) and may want something from one or several of the other providers. All services are performed at a cost (the value of ‘money’ that is used up to produce something) that is supported by the provider.

For instance, in case equipment acts as provider and pallets as requestors, the services provided are processing capabilities, at any degree of granularity (sensors / machines / factory automation cells). Pallets request these skills and are willing to pay for acquiring them faster than their competitors. The ‘money’ paid by a pallet must be equal or higher than the price set by the machine, and it has to be expressed in a unit of measure that is valued by both provider and requestor. The cost of performing the service must be expressed in a unit of measure that quantifies what is spent to perform the service and at the same time is relevant to the other entities in the illustrated setting (e.g. energy consumption).

When pallets act as providers, the service provided is transfer to the physical location of the requestor (the workstation). Each workstation seeks in-place pallet positioning for onsite further processing. The goal is to minimize the amount of time a processing station spends unoccupied, and each workstation is willing to pay a price for achieving this target more frequently than their competitors.

In this case, prices depend on the physical distance between the requestor and the provider, and it may vary depending on who requests the service, priority level assigned to the requestor, possibilities to offer extra needed services to the
requestor, in addition to the one already requested (could pallets function as energy providers themselves somehow? Can pallets function as energy harvesters?). The cost associated to the offered service is the energy consumption of the pallet transfer from the source point to the destination point (the physical location of the invoker).

A Price-as-a-Reward mechanism is implementable for all types of providers. Workstations could set lower prices depending on whether requestors use their awareness of energy prices for the overall well-being (bringing less energy consuming processes to the workstations requiring more energy when prices are at their peak during the day / asking for more energy intensive services during energy prices’ valley moments). Pallets could set lower prices depending on whether they estimate transportation to requestor location would be lower in terms of energy consumption than other alternatives.

<table>
<thead>
<tr>
<th>Services offered</th>
<th>Workstation</th>
<th>Pallet</th>
<th>Lighting provider</th>
<th>Energy provider</th>
<th>Energy Advisor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processing</td>
<td>Transportation to in-place location</td>
<td>Context-Adjusted Lighting</td>
<td>Energy</td>
<td>Advice (who should do what when using what amount of energy)</td>
<td></td>
</tr>
<tr>
<td>Requested</td>
<td>In-place positioning Energy Context Adjusted Lighting</td>
<td>Equipment skills Energy Context-Adjusted Lighting</td>
<td>Advice Energy</td>
<td>Advice RT Information</td>
<td></td>
</tr>
<tr>
<td>Profit and Profit seekers</td>
<td>Profit Seeker</td>
<td>Profit Seeker</td>
<td>-</td>
<td>Profit Seeker</td>
<td></td>
</tr>
<tr>
<td>Currency</td>
<td>Energy</td>
<td>Energy</td>
<td>Energy</td>
<td>Energy</td>
<td></td>
</tr>
<tr>
<td>Price</td>
<td>Set by provider. Paid to the workstation. Price-as-a-Reward (lower if some precondition is met by requestor).</td>
<td>Set by provider. Paid to the pallet. Price as a Reward</td>
<td>Set by provider. Paid to the lighting provider</td>
<td>Not needed</td>
<td></td>
</tr>
<tr>
<td>Price-as-a-Reward Precondition</td>
<td>Lower price imposed e.g. if a pallet seeks the machine during ‘valley’ times with energy consuming processes</td>
<td>Lower price imposed e.g. for machines that are closer physically to the pallet (so that transportation is not so energy consuming)</td>
<td>-</td>
<td>Not needed at the moment</td>
<td></td>
</tr>
<tr>
<td>Cost</td>
<td>Processing cost of a pallet (Energy consumption)</td>
<td>Transport cost to in-place (Energy consumption)</td>
<td>Energy consumption of the lighting service</td>
<td>Energy consumption associated to the transportation of energy to the requestor</td>
<td>Not needed at the moment</td>
</tr>
</tbody>
</table>

4. CONCLUSIONS. FUTURE WORK

This paper discusses from a general viewpoint the applicability of market based competition models such as Cournot and Bertrand for energy efficient manufacturing settings. The factory automation settings taken into consideration have players from all levels of the enterprise (MES and ERP), which act both as providers and as requestors of energy-relevant services.

Although other models (e.g. the trophic representation) could be interesting for evaluation, the discussion here focuses on a who wants - to buy what - from who - and for which price viewpoint.

Attempts to correlate concepts in economy with corresponding implementation possibilities in the presented application domain are presented.

Research should also evaluate quantitatively what happens when players of the same “species” (e.g. pallets) act both as providers and requestors from each other (would this be a form of cooperation rather than competition?). Setting the price could incorporate both energy and priorities. How would setting the price by consumers instead of providers influence overall system behavior? Could pallets offer more than transportation services to in-place locations (e.g. could they become small energy harvesters within the line?) Which paradigm would work better from the viewpoint of overall energy optimization? Would a ‘sallary’ based mechanism work in such a setting? What would then be the ‘startup fund’ of the players? Apart from energy, what other currencies would be valued by all presented actors?

The list of open questions could go on. Future implementation of the proposed approach in a real factory automation setting and performance evaluation would hopefully resolve many of these questions and raise many new ones.

REFERENCES

