Market data model, Multicommodity market, Network systems

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M^3: OPEN MULTI-COMMODITY MARKET DATA MODEL FOR NETWORK SYSTEMS

We present an open Multi-commodity Market data Model (abbr. M^3) that may be used in designing information systems for market balancing and clearing in the context of multi-commodity trade in various network infrastructure sectors. A system of definitions has been developed that promotes clear understanding and standard interfaces for the data flows and integration of market data and processes across societies. M^3 is a set of formal data models, which results in XML-derived information interchange specification.

1. INTRODUCTION

Complex systems are often beyond efficient direct control and management. Thus, during the past decades, the world-wide market liberalization and deregulation processes are being implemented in many network infrastructure sectors, including power systems, telecommunication, computer, rail and transport networks, water, urban systems and others.

Under deregulation, the systems are undergoing drastic restructuring and transformation from cost-conscious, regulated utilities to competitive market participants. These entities have their own independent interests, values, different tasks, operations and services. State-owned or private monopolies, that have been functioned traditionally in the infrastructure sectors, are being gradually transformed into various market entities, which must operate in new competitive market environments, under regulated market rules, with operational help of various market institutions, such as auctions, commodity exchanges, real-time balancing markets, etc.

In the deregulated framework for control and management, instead of operating according to central rules and plans established by a hierarchical control structure in a centralized system, the systems operate through cooperative behavior of many entities which interact as the competitive market participants. The need for better management and control of large distributed network systems stimulated in research community a great deal of interest in developing new competitive market mechanisms for management and closed-loop operational control procedures to help system performance optimization. An important stream of the research work on market development is

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focussed on gradual functional decentralization with allocation of obligations and rights to distributed market-players. On another side, some market integration processes are also enhanced.

One difficulty is in analyzing and comparing different market models, methods, experiments and solutions in a reliable way, due to heterogenous experiment environments, different data models, and various numerical data and data storage methods that are used. However, the market models that are different at a first glance, in fact operate on the same types of data. Moreover, only the best auction clearing mechanisms verified by many researches in multiple experiments can be implemented as practical solutions. Therefore, from perspective of serving the development and verification of new auction mechanisms, the open market information interchange systems, including data models, are extremely important for the future of the network industries.

The market processes consist of a sequence of many elementary balancing and clearing processes that tend towards a complete system`s balance at a real time. Usually, each process has its own mechanism for information interchange and processing. At present, there are no general world-wide standards for information interchange mechanisms. In some industries there are data interchange mechanism which can be acknowledged as local standards, for instance, RosettaNet standards in electronic industry, MDDL (Market Data Definition Language) in financial sector and other industries standards specified on the basis of open standards like ebXML (Electronic Business using eXtensible Markup Language) or XBRL (eXtensible Business Reporting Language), see [13][14][16]. However, these standards are focused on electronic communication of business and financial data like invoices, offers, business partner information and so on. In energy sector – a typical infrastructure market – UCTE (Union for the Co-ordination of Transmission of Electricity) initiative called Electronic Highway focuses only on transport layer and technical aspects of the communication network. It is clear that existing standards cannot meet the needs of the infrastructural sectors, where many specific elements, related to real-time balancing of many commodities and services under constraints, may play important roles. Heterogenous systems and absence of general mechanism for data interchanges create barriers for mechanism integration and developments that are especially important for the European and world-wide market evolutions.

Market entities create, process, and consume extensive volumes of market data and must deal with dizzying collection of sources, necessary to conduct market operations. Data users need to devote considerable resources in translating data from multiple sources. In order to integrate various market solutions and to ease mappings between various market data applications and systems, we have designed an open Multi-commodity Market Model (abbr. M^3) that may be used both in research works and in operation of the market balancing and clearing systems in the context of multi-commodity trade, see [15]. A system of definitions has been developed that promotes clear understanding and standard interfaces for the data flow. The common market data terminology embraced by M^3 allows us to clearly state the nature and origin of the structured market data elements, thus removing ambiguity.

M^3 is a set of formal data models, which results in XML-derived information interchange specification [15]. The particular advantage of M^3 is that it may help the designers to conduct some development simultaneously and to some extent independently, whereas, thanks to a unified model, data and results may be easily exchanged or/and shared between the users of various market clearing systems. M^3 may be useful in facilitating communication and coordination between subsequent market sub-areas and stages. It may be very helpful both for the market operators as well as for the market users, as it facilitates data exchange procedures between the market operators and market users. It may also helpful in achieving the long-term benefits of interoperability and enhancement of market integration and quality of market products.

An important goal of M^3 is also to integrate market data from multiple distributed sources in diverse systems throughout the global "enterprise" network without having to understand how information providers format and normalize internal processes and data. The payoff is to shift the focus of internal efforts from issues associated with the "formatting of data" to those associated with the "quality of processes" to enhance the market functionality.

In our approach a single balancing process is treated as a "black box", which transforms some input data (market offers, network data, initial programmes, etc.) into output data: market prices, settlements, updated programmes, etc. We make no assumptions concerning the way how the input data can be processed. Thus, the process can be a pure auction or exchange mechanism, the real-time balancing, or any other balancing or clearing process. The elements of the open data model for the market systems include, among the other things, data for network modelling, market entities structure, commodities structure, offers, network system constraints, and individual constraints of the market participants. Fig. 1 clarifies which data are inputs and outputs of the process.

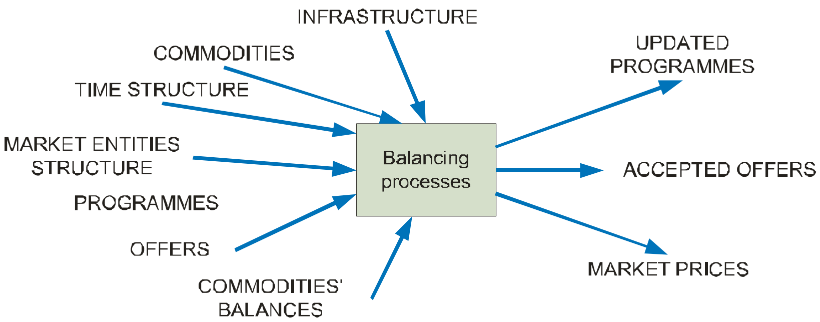

Fig. 1. Data in a single balancing process

One of the essential aspects of our open data model is that it is an extremely flexible tool for modelling various types of offers and bids. In particular, it comprises simple offers – typical for currently available market solutions, integrated offers – dedicated for multi-commodity trade, and grouping offers – necessary if some requirements for individual ancillary services are additionally required. The second important aspect is that the open data model allows us to use different networks models including the basic and virtual ones. Each network can be used for modelling a subset of commodities turnover, while the basic network can be used to model technical aspects together with security and resource requirements.

The paper is organized as follows. In the next section the requirements for developing new market models are discussed. In section 3 the basic formal elements of the M^3 data model are formulated. The formal model is followed by some potential applications of the M^3 model outlined in Section 4.

2. MARKET DESIGN ISSUSES

At present, in many network industries, functionalities of the existing market designs are not completely satisfactory. For a complete successful market system design, reactions to all operational situations should result from market-driven processes for achieving economic market equilibria, together with considering technical and operational conditions, resource constraints and/or automatic control system requirements. Due to operational and real-time requirements existing in such systems, specific problem-oriented market designs are usually required.

Many researches and professionalists around the world participate in development, investigation and implementation of a variety of new ideas related to auction and market clearing systems under various market conditions. At present, there are no conformity in the research directions that can be considered as the most promising ones. Despite a tremendous world-wide research it seems that the decision makers still do not possess enough knowledge to direct the market evolution and support the best directions in which the market systems should evolve.

In the network systems, an efficient market balance may be obtained in a single balancing process by joint optimization of trade of many elementary commodities and services related to buy and sell offers of the network resources. For this purpose the multi-commodity exchanges can be used, in addition to single-commodity exchanges and bilateral trading. The basic multi-commodity market clearing model [12] is in the LP form and enables maximizing global economic welfare and effective balancing of sell and buy offers for bundles of elementary commodities. It has all positive features of the classical single-commodity market clearing model, yet enabling handling many real-world requirements.

Apart from traditional auctions, long-term and medium-term single-commodity market segments, or day-ahead and intra-day-markets, there is a need for designing specific problem-oriented multi-commodity auctions and balancing market mechanisms, which must provide feasible execution of sales contracts and assure timely delivery of many goods and services.

In the case of infrastructure sectors, implementing free market trading appears to be significantly harder then in the other sectors. Trading and deliveries of goods and services usually needs some limited resources. Existence of various resource constraints strongly contributes to some costs and occurrence of the local market power. Resource limitations reduce the freedom of the market competitive solutions and may decrease profits, i.e. values of the economic wealth that would result from the free market trade. Moreover, other more technical and security aspects, that influence the market solutions, must be taken into account. A more general multi-commodity market clearing model developed in [12] is in the MILP form. Multiple clearing on forward and real-time market segments assures that the supply and demand for many goods and services can be matched simultaneously in real time under various constraints and requirements.

Achieving efficient market equilibria in constrained network systems in real time is a challenging task for researchers. Various market segments must be designed for ensuring safe, feasible and economically efficient system balances, that can be achieved in real time in all possible operational situations. The forward and real-time balancing markets should also allow the market players to change their preferences and to modify correspondingly the offers and bids, in a short time just before delivery. In this way the market players may react to rapid changes of the system state. Apparently, also the closed-loop feedback control system must be harmonized with the real-time market processes.

In this paper we address appropriate market design issues and control mechanisms for distributed networks. One purpose of the open M^3 model is that it creates a flexible framework for development of new market models and algorithms, benchmark data repository, and gives possibility for integration of software components which implement balancing mechanisms. Finally, it will help the community to determine the best industrial standards of data interchange and enable for an easy public access and exchange of various market data.

3. ELEMENTS OF M^3 – A FORMAL MODEL

We consider simultaneous trade of many commodities on the market, where many separate, independent or dependent balancing processes form a complex market system. Individual balancing process is a smallest processing block. Its role is to transform the input data: market state information, market resources, participants' offers, into the output data: new state of commodities and resource allocation (under market balance), decisions related to acceptance or rejection of offers, market prices and balancing costs.

In a given time slot individual balancing processes can be performed either in parallel – it is the case of independent balancing on the competitive platforms – or in sequence, when next execution of the balancing process concerns the same set of commodities (iterative balancing) or related commodities (e.g. repetitive balancing with the shifting time window). Output data of one balancing process typically feed the inputs of one or more other processes. Moreover, it is often necessary to convert the data for the sake of different time structures (balancing in the scale of year and next in the month, day), different infrastructure areas (trading on the continent area, sub-regions and zones), commodities (trading aggregated commodity first, and then trading elementary commodities), or some other reasons. Finally, structure of the balancing processes and relations between processes can be very complex.

In this paper we focus our attention on modelling the data structure of a single balancing process. The process is perceived as a “black box”, and thus it can be implemented in any way. We assume that we do not know how the data are processed, we only know data categories that can appear on the input or output of the process. In particular, we may consider balancing process that determines the volumes of accepted offers without specifying financial flows – so called *quantitative balancing* – or we may consider value balancing (calculating market prices, fees, and costs).

Bellow we discuss individual components of the data model for a single balancing process. Most of the components such as infrastructure, market entities, time structure, commodities, balances, only appear as an input data. Other components, like programmes, offers, and market prices can be input and/or output data of the balancing process.

For simplicity we omit identifier (index) of the balancing process.

3.1. NETWORK INFRASTRUCTURE

Physical commodities exchange between market participants requires a technical *infrastructure* to assure feasible delivery of services and goods. Examples include telecommunication networks, roads and railways networks, transmission lines for the electricity, and so on. Thus the *infrastructure* plays the role of a system of limited resources during the balancing process. In the other words, *infrastructure* is a medium for delivery of commodities and services. However, a single balancing process may require different infrastructure models for different commodities. Moreover, the balancing process can integrate two aspects: pure trade operations and technical requirements to assure feasibility of trade operations. Both of them may require different *infrastructure* models, e.g. pure trade may be considered on national level, whereas feasible deliveries may need sub-regional, or zonal, resources. Therefore, many *infrastructure* models should be provided to balance the market. The most detailed *infrastructure* model is called *basic net*. Since other models of *infrastructure* aggregate the physical resources at some level of abstraction, we called them *virtual nets*. We model *infrastructure* as the set N of network models, where n-th network model is a parameterized graph $(V^n, E^n, P^{V^n}, P^{E^n})$, where $n \in N$ is an index of the net model, V^n is a set of nodes, E^n is e set of edges, P^{V^n} and E^{V^n} are parameters of vertices and arcs respectively. The semantic of parameters can be different, but typical parameters related to edges represent the capacities and parameters related to nodes that define admissible levels of commodities in a given node.

Virtual network is an aggregate of the *basic network* or other *virtual network*. There can be many aggregation schemas in parallel, however only relations between nodes in different nets are important, but not the relations between whole networks. Fig. 2 shows an example of five networks and their aggregations.

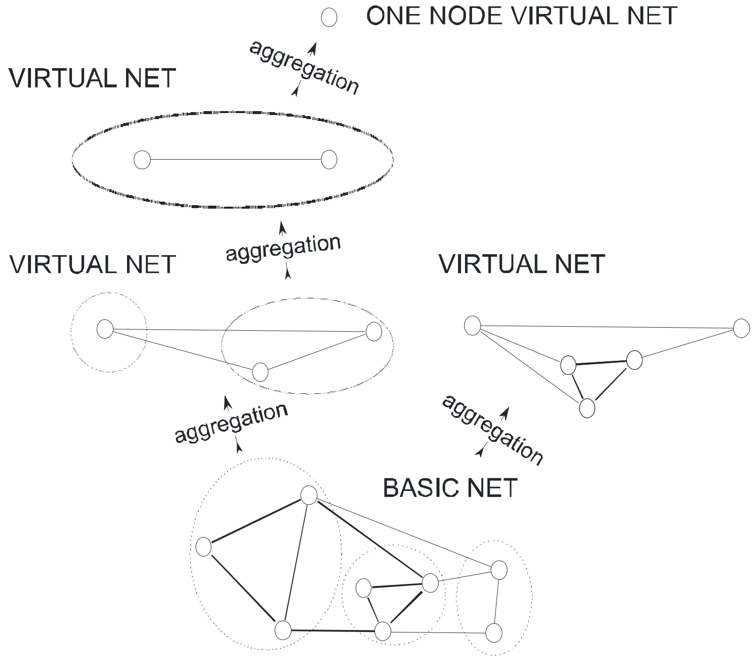

Fig. 2. Example of *infrastructure* model consisted of five networks

3.2. MARKET ENTITIES STRUCTURE

Structure *market entities* describes market players and relation between them. The *market entities* are modelled as an acyclic oriented graph, as shown in Fig. 3.

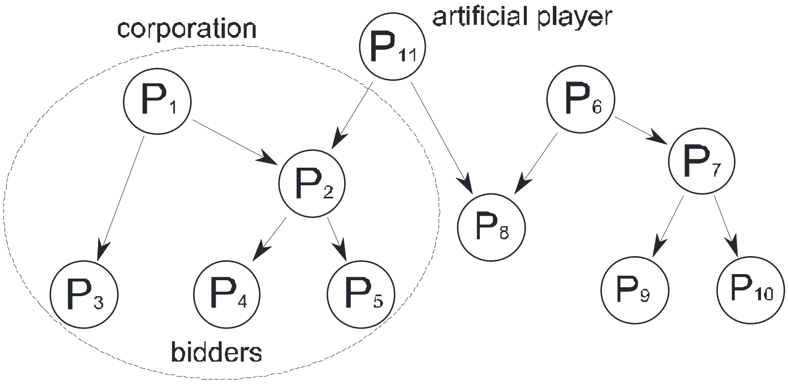

Fig. 3. Example of *market entities*

Market entities form a hierarchy, where given market entity may be composed of some other market entities, e.g. a corporation and subsidiaries. Different market entities may be involved at different stages of balancing process, e.g. on electrical energy markets each generation unit bids a sell offer, while the whole power plant is involved in settlements.

It may be convenient to introduce some artificial (*vitual*) market entities. Such market entities may represent groups of players distinguished by a certain feature, e.g. location in a given area, or production technology. Virtual market entities are useful to filter the groups of market entities that require some additional resources.

We define market entity p from set of market entities P, as a set $\langle id,type,node,\{set\ of\ successors\}\rangle$, where id is an identifier of market entity located at node $node$. Set of market entities' types is specific for a given industry or market. Set of successors defines a graph model for market entities structure.

3.3. TIME STRUCTURE

Schedule of commodities' deliveries which can be produced by the balancing process is strictly related to *time structure*. Commodities are delivered in determined time slots. Thus the time horizon must be divided into time segments and every commodity is related to a time slot. However, trading different commodities may require different time slots, e.g. some commodity may be sold for an aggregated time slot, let's say – month, and some other commodities can be offered for shorter periods, say days, or hours. Moreover, a commodity can be offered to deliver only during the working days, peak hours, etc.

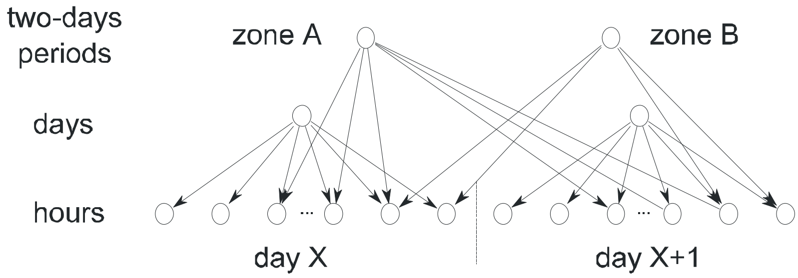

Fig. 4. Example of *time structure*

Fig. 4 shows an example of *time structure*. The *time structure* is a acyclic directed graph $C=(V^C,E^C)$, where nodes V^C define time slots, and edges describe aggregation between time slots. In most systems only one *time structure* is in a single balancing process.

3.4. COMMODITIES

Let T denote the set of commodities' types that are specific for a given balancing process. Commodity c is described by the set $\langle t,v,e,d,P^t\rangle$, where $t\in T$, $v\in V^n$, $e\in E^n$, $n\in N$, $d\in V^C$. Commodity can be related to a node v from *infrastructure* model or to oriented edge e from the same *network* model. Parameter d is a time slot from time structure $C=(V^C,E^C)$. P^t describes set of parameters for commodity types t, e.g. realization date for options.

Observe that single commodity is always related to a single node or edge of the *infrastructure* model and a time slot. Nevertheless, it can be assigned to the root node of the most aggregated network, which means the “whole market”. Thus the semantic is the following: “commodity is on the whole market and can be traded”. The same way of thinking can be applied for time slots.

3.5. PROGRAMMES

Programme is a current schedule of delivery of some commodity for one or more market entities. *Programme* can be produced by balancing process as the result of accepting some offers.

Programme may also be an input data for some balancing processes. In this case it informs about the current overall status of the market entity contracts in a aggregated way.

Programme is defined by $\langle id,entity,commodity,volume\rangle$, where *id* is an identifier of *programme* for a given *commodity* and a given market *entity*. Market entities are going to deliver/buy or should deliver/buy the commodity at level *volume*. The semantic depends on the context: whether it is input or output, kind of balancing process.

3.6. OFFERS

Definition of offers and its types is the most important and powerful element of multi-commodity balancing models. There are three types of offers: *simple, integrated* and *grouping* offers.

We define *simple offer* by $\langle id,enity,commodity,share\ factor,offer\ price,domain\rangle$. Each offer is uniquely identified by its *id* – this means that every market entity can submit many offers for the same commodity. Share factor can be equal 1, which means selling "to" the market, or -1 which means buying "from" the market. The offer price is a minimal or maximal unit price that market entity demands for selling or buying offer respectively. The *domain* describes the admissible volumes of commodity that is offered during the balancing. In the simplest case the domain can be defined by range $\left\langle 0, p^{\max} \right\rangle$ which means that offer can be accepted fully at level p^{max}, partially at level less then p^{max}, or it can be rejected. Another typical possibility is the case of discrete sets – an offer is accepted fully or rejected. A more general case of the domain is $\{0\} \cup \left\langle p^{\min}, p^{\max} \right\rangle$ – offer is either rejected, or, if accepted, it`s volume must be accepted at least at the minimum level p^{min}.

The second type of offers is *integrated offer*. This is a typical type of offer for multi-commodity turnover, where players trade with packages (or bundles) of commodities with fixed proportions of commodities in the offer. In comparison to the *simple offer* the only difference is that there is known the vector of share factors – each factor for each commodity. A share factor is positive, if the related commodity is offered for sell, or negative, if it is offered for buy. In a single *integrated offer* some commodities can be offered for sell, while others for buy. The offer price is a price for a unit of package of commodities. The accepted volume is scalar for the whole package of commodities. Thus the domain is one dimensional.

The most complex type of offers are *grouping offers*. *Grouping offers* allow the market entities to define individual constraints. Satisfying a single constraint can be treated as an individual service. For example, power generation unit needs to be started-up before power production, thus an individual start-up service must be provided. Of course, grouping offers can be used to describe much more complex relations.

Grouping offer is described by $\langle id, entity, (offers), G, Y\rangle$. *Grouping offer* aggregates a set of other *simple* or *integrated offers* and describes relation between these offers. There are no price of acceptance, because the relations in the grouping offer must be satisfied after balancing. However, as a result of balancing, some cost can be assigned to such offers. *G* is a multidimensional function of aggregation that concerns offers included in the *grouping offer* and *Y* is an admissible range of aggregation domain.

In a linear case *G* is represented by matrix of coefficients $I \times |J|$, where *I* is the number of constraints (aggregation functions) and *J* is a set of offers to aggregate. Then *Y* is a vector of size *I*, each element of vector is an interval defining admissible domains of the related aggregation. Let us assume that vector p^J is an accepted volumes of each offer from set J derived from some balancing algorithm. Then the balancing algorithm must assure that the following constraints are satisfied: $Gp^J \in Y$. In a simpler case elements of Y are scalars – the maximum of admissible level after aggregations.

Every offer can also be an output data for balancing process which brings some information about balancing results. However, in this case any "output" offer is enriched by accepted volume in a range described by its domain, and price that the offer is paid.

3.7. BALANCE OF COMMODITIES

For each elementary commodity traded during the balancing process some conditions of balance is required. For the commodity c the balancing requirements are defined by pair $\{b_{c^{\min}}, b_{c^{\max}}\}$, which means that the difference between aggregated supply of commodity c and the aggregated demand must be in a range of $\left\langle b_{c^{\min}}, b_{c^{\max}} \right\rangle$. In case of $b_{c^{\min}} = b_{c^{\max}} = 0$ the demand must be balanced exactly with supply. In case of nonelastic demand where no demand offer is considered, the stiff demand is provided by $b_{c^{\min}} = b_{c^{\max}} \geq 0$.

3.8. MARKET PRICES

Market prices are the output data of the balancing and clearing processes. To satisfy requirements of various clearing processes we provide two market prices for each commodity c: π_c^B – buy price or π_c^S – sell price. Thus, the market prices are described by the set of triples $\left\langle c, p^B, p^S \right\rangle$ for each commodity c.

Fig. 5 shows only part of M^3 model potentiality. Nevertheless, it is clear that M^3 can describe huge variety of market balancing processes. For instance, commodity *com_1_5* represents an commodity available at node 5 of basic net and is delivered during the first hour of working day N. At the same time commodity *com_B_2-4* is related to bigger territory – whole REGION B, and can be offered for a long period composite of smaller intervals. Any middle solutions are also acceptable.

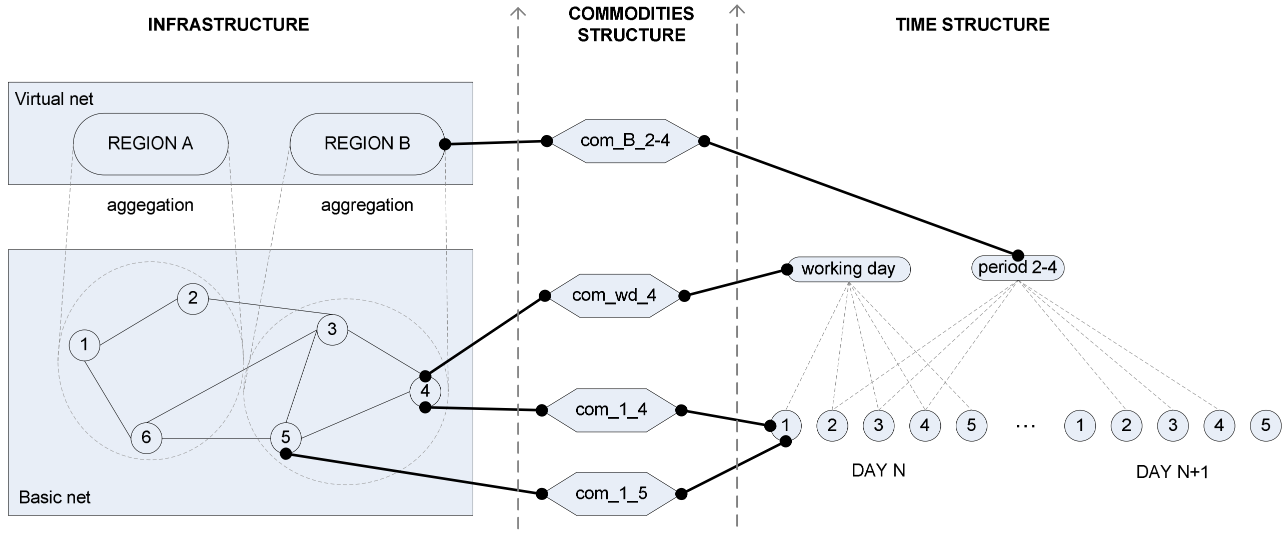

Fig. 5. Infrastructure, market entities and time structures example

4. APLICATIONS OF M^3

In most cases, market clearing rules can be based on solving an optimization problem, e.g. maximizing the social welfare or minimizing the total procurement cost. Even when offers and bids are simply sorted and matched, the problem can be stated as a trivial optimization task. Apart from the balancing model, the clearing conditions can be formulated in four categories: the targets that the balancing process aims (*objective*), *commodities' balances*, *system constraints*, *individual constraints*. Elements of M^3 play a role of data sources for each balancing model category, e.g. objective "social welfare maximizing" can be built on the basis of market bidder, commodity and time element dictionaries and offer prices included in the bidder offers. The most noticeable advantage of data model M^3 is the fact that aside from market model, M^3 is able to describe and provide data for extremely wide class of infrastructure market clearing (balancing) rules. Below we outline some of typical market solutions where exchange and delivery of commodities require some specific infrastructure, that limits the freedom of trade and thus M^3 can be applied.

Modelling class of various telecommunication, transportation and power systems requires large amount of data concerning technical constraints. Part of these data is known to market operator, whereas other may be included in market entities offers. There are usually a lot related commodities, thus market entities should have possibility to submit multi-commodity offers for some groups of commodities tied-up with each other. Consequently, offers and all other data exchanged in the market may be quite sophisticated, but M^3 with its integrated and grouping offers meets such requirements. Potential applications of M^3 may include various auctions, for instance Airwaves Auctions and Takeover Battles [8], combinatorial auctions, for example auctions of trackage rights [4], [3], telecommunication networks with Quality of Service (QoS) mechanisms [9], and also various power market systems [10].

Important group of market models are real-time (balancing) systems, where production and delivery of commodities must be balanced in a real time subject to system constraints assuring feasibility of the system operation together with efficient production and maximization of the social welfare objective function, see [1],[2]. We may rate many markets among above-mentioned category, e.g. a range of *intra-day* and *Real-Time Markets* (RTM) [11], which are commonly used in various systems where the real supply and demand can not be precisely predicted in the forward market segments and only forecasts can be used. M^3 meets all RTM's requirements and allows to exchange fast, easily and reliably all necessary data.

Other classes of balancing processes for which M^3 adequately describes required data include mulit-stage markets – where the whole market balance is obtained as a result of number of consecutive balancing processes, multilateral distributed multi-agent market systems – where clearing is performed in distributed environment of different points of service. For more detailed examples see [7] and M^3 project website [15].

5. CONCLUSIONS

The paper presents the overall design of the open multi-commodity market data model. The proposed model M^3 has many potential practical applications. As it was shown, M^3 may be used in a wide range of market-oriented network systems and may significantly facilitate communication, coordination and modelling procedures, both from the market operators and market entities point of view.

It may be used in designing information systems for market balancing and clearing in the context of multi-commodity trade in various network infrastructure sectors. M^3 provides a set of formal data models, which results in XML-derived information interchange specification. The unified data model may enable cooperation and easy data exchange between different research teams, as well as the market entities.

6. ACKNOWLEDGMENTS

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