Hierarchical Planning for Industrial Product Service Systems

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Abstract

Industrial Product Service Systems (IPS²) are an innovative business model for engineering enterprises, integrating products and services. A substantial portion of later operating costs is determined by decisions in the design phase. This leads to a hierarchical problem structure: On the strategic planning level, configuration of IPS² is accomplished regarding customers' requirements and uncertainties. Revenues and (adaptation) costs during the subsequent delivery phase have to be anticipated. The operative planning level is concerned with the use of a given IPS². Later changes of business models are only possible within the scope of the strategic plan. The more uncertainties strategic planning faces, the more flexibility has to be provided in order to assure a successful coordination of both levels.

Keywords

Strategic Planning, Flexibility, Hierarchical Planning, Uncertainty, Cost Model

1 INTRODUCTION

The business situation in the field of mechanical engineering is characterized by increasing international competence. As manufacturing facilities become more and more interchangeable, margins are decreasing. Thus enterprises are forced to shift their activities to new products, new market segments and new business models which allow them to differentiate from competitors and to improve their income situation.

In recent years the additional offer of **industrial services** has been chosen as such a means of differentiation. But they face two main problems: On one hand, offers are often developed rather unsystematically which leads to an uncoordinated set of services whose benefit for the customer is suboptimal. On the other hand, customers tend to accept services as most welcome add-ons but show only a low willingness to pay additional charges.

Industrial product service systems (IPS²) are a new approach to solve this problem. They integrate the customer into the whole process of provision – covering the engineering phase as well as the utilization phase. Therefore they are characterized by a high degree of customization. The planning of activities concerning IPS² is a challenging task that has to meet many demands.

The paper deals with the **hierarchical approach** for planning activities concerning IPS². It is organized as follows: The focus of chapter 2 is to give an overview about the concept of IPS², its origins, its characteristics and the various business models. Chapter 3 presents a general introduction into the theory of hierarchical planning including its basic elements and its fields of application. In chapter 4 the hierarchical planning approach is applied to the problem setting of IPS². Adequate models for the strategic and the operative planning level are formulated and coordinated according to their specific needs. Finally, a survey of future areas of research is given.

2 INDUSTRIAL PRODUCT SERVICE SYSTEMS

2.1 Origins of IPS2

In science and practice the advantages of integrating products and services are discussed from a strategic management perspective. Challenges related to this integration are often neglected. However, the transition from a product manufacturer to a service provider constitutes managerial challenges. [1]

On the one hand, different economic principles respectively characterize the product and service business. Service provision requires organizational principles, structures and processes which are new to many product manufacturers. On the other hand, the management faces new challenges due to the change of the business model. The integration of services into the core products effectuates a **modification of the business relation** from a transaction-based relation to a contractual relation (relation-oriented business model) which takes place over a longer period of time. For this relation new incentive structures are decisive.

Companies pass through various stages on their way from product manufacturers to producing service providers, problems of organization and planning as well pricing and managerial accounting need to be solved for any stage. According to the empiric-based phase schema by Oliva and Kallenberg, [1] one can differentiate between four phases, respectively **four types** of providers of industrial services:

- The first phase is characterized by a **consolidation** of transaction-oriented services. Services are provided by different organizational units, their only aim being the increase of product sales. Services are billed implicitly via the price of the product. An important part of this phase is the introduction of information instruments in order to control the contribution of the services to success and quality. From the managerial accounting point of view, providers profit from a refined cost calculation in the service area.
- The second phase is characterized by a **reorganization** of organizational structures and processes, which is triggered when the industrial services enter the market. Providers of the second phase have an extended range of services with individual prices. Managerial Accounting is particularly interested in aspects of capacity planning. Due to the organizational independence, the service sector gains

responsibility for the results and for its own controlling system.

- In the third phase, the interaction with the customers changes from a transactional exchange to an **interactive, relational process**. Instead of billing each individual service cost-plus, so-called full-service contracts specify a fixed fee for all services within a specific period of time. According to Oliva and Kallenberg, typical services provided in this phase are, apart from maintenance and service contracts in the form of a full service, preventive maintenance, equipment condition monitoring or spare parts management. [1] Usually, full service contracts include an improvement of operational availability and response times in case of failure. The advantage of such contracts is the better use of the capacities created in phase 2. The revenues are not only higher, but also more predictable. Due to shifting the cost risk from the customer to the supplier, the planning of the variable costs and the price setting is crucial to the companies of this type. It is decisive to know the frequency distribution, i.e. the risk of default.
- **Process-oriented services** are added to the offer of industrial services in the fourth phase. This is connected to a change of paradigm, which changes the focus of the value proposition to the end-users. Focus is no longer on product efficacy – whether the product works – rather the effectiveness and efficiency of the product within the end-user's process is now the relevant issue. [1]

  Following such customer-oriented strategies, i.e. centering the offering on the end-user's process, dissolves the boundary of products and services. Most companies' offerings in this phase can at best be characterized as bundles of product and services (IPS²), that constitute a problem solution to individual customer needs along the life cycle of the installed base.

  Challenges for the management result from the dynamics of IPS²s. It mainly has to adjust problem solutions via the whole life cycle to changing general conditions. Flexibility, as a strategic factor for success, gains importance in this context. It is the task of managerial accounting to support the creation of flexibility potentials in order to reduce costs and to develop corresponding strategies already in the early stages of IPS^2 development. [2]

In the following two subsections, the concept of IPS² and the related innovative and flexible business models are introduced.

2.2 Structure of IPS²

IPS² are characterized by an integrated and mutually determining process of planning, development, operation, and use of goods and services. They constitute a problem solution for **business-to-business markets**, tailor-made to individual customers' needs along the IPS² life cycle. Customizing an IPS² and integrating flexibility is based primarily on the possibility of partially substituting product and service components to meet customer requirements. As illustrated in Figure 1, IPS^2 are composed of pure product modules, pure service modules and hybrid modules that combine specific products and services.

The definition given above allows **different designs** of IPS². They are able to cover all market requirements due to the substitution option between the portions and specifications of products and services. These include the sale of a product, where the customer is responsible for all maintenance activities after the purchase, to complex user models, where the supplier is responsible for all production processes. This setting is the background for a first attempt to classify such product/service combinations in literature [3].

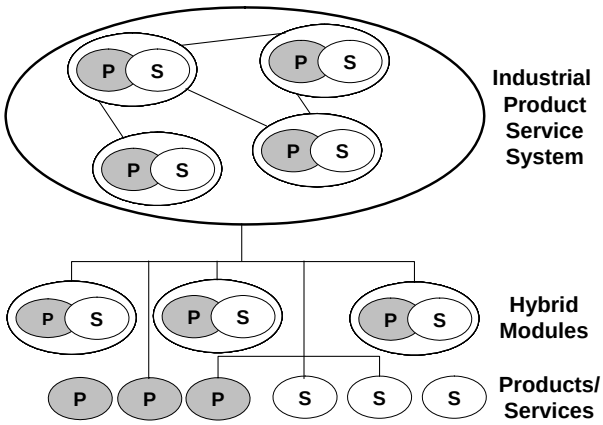

Figure 1: Structure of IPS². [5]

A further separation of IPS^2 is to follow. A central criterion for differentiation is the **system complexity** so that IPS² can be considered to be little to very complex. Various features influence the complexity of the system:

- Type of customer benefit;
- Range of services offered;
- Amount and heterogeneity of individual part of an IPS^2;
- Degree of technical integration in the value added domain of the customer;
- Degree of individualization;
- Temporal dynamics and changeability of the service provision.

The features "individualization" and "temporal dynamics" are of great importance for the planning problem focused in this contribution because there is a potential trade off. On the one hand, the orientation towards customer benefit with an IPS^2 requires that the individual parts will be developed with regards to specific **customer requirements**. This leads to a technically integrated development of the individual parts of an IPS^2, since the value that can be created exceeds the value generated by purely adding values of individual parts. The higher the degree of integration, the more complex the system becomes. At the same time it is also more difficult to substitute individual parts for the competitors.

On the other hand, within an IPS^2 service provision the interaction with the customer will cover a **longer period of time**. From this it follows that a possible adjustment of the IPS^2 in the use and operating phase becomes necessary, which will lead to an increase of complexity, too. It is a general fact that the complexity of IPS^2 increases the longer the use and operating phase is. The higher the degree of technical integration of an IPS^2 is, the more difficult its adjustment might be.

2.3 Business Models for IPS²

Innovative and flexible business models which describe the form of relations between the customer and supplier are based on these dynamic IPS^2. A **business model** is a model, which, referred to a business operation, represents the following features: [4]

- The **participants**, their roles and their contribution to the value added (architecture of value added),
- the **benefit** that the customer or other participants can gain from the business operation (value propositions), and

	Function Oriented	Availability Oriented	Result Oriented
Design Object	Potentials	Processes	Products
Basis for Billing	Machine	Hours of Operation	Number of Items
Typical Services	Maintenance Replacement	Monitoring Preventive Maintenance	Solution of Customer Problems
Ownership	Customer	Customer or Supplier	Supplier
Responsibility of Supplier	Machine Quality	Process Quality	Product Quality
Risk of Supplier	low	medium	high

Table 1: Characteristics of IPS².

- the **source of income** resulting from business (revenue model).

The business model is an instrument for strategic planning and communication between all participants – investors, members of staff and customers.

Depending on the value proposition, we differ between three business models for IPS² [5]:

- A **function-oriented business model**, for example, includes a maintenance contract in order to guarantee the functionality for a specified period of time.
- An additional availability of the facility is guaranteed in the **availability-oriented business model**, where, for the first time, the supplier is solely responsible for business processes of the customer, thus bearing a share of the production risk. His responsibility covers all processes which guarantee the availability, i.e. maintenance or preventive servicing.
- In a **result-oriented business model**, the supplier is responsible for the production results, as the customers will only pay for faultless parts.

The main characteristics of the three business models for IPS² are summarized in table 1.

The supplier takes over additional tasks, which were originally carried out by the customer, as there is a consequent orientation of the service offer to the individual customer's benefit. The customer-supplier relation changes to an **integrative cooperation**, where the established role perception between supplier and customer, depending on the corresponding business models, dissolves more or less. In general, the business models differ in the ownership structure of the product. While traditional business models are based on the transfer of the ownership rights to the customer, the customer is not the owner of the product he uses in innovative business models. The supplier remains the owner.

Business models are important, as they influence the incentives of all parties involved in the business relation. Basically, innovative business models are better suited than traditional ones in order to harmonize the interests of the cooperation partners and to create incentives [6]. Sometimes the choice of the business model depends on the type of the product, respectively on the complexity of IPS² [7].

3 HIERARCHICAL PLANNING

3.1 General structure of hierarchical planning

Hierarchical planning is an approach used in order to reduce complexity of global planning problems. **Complexity** may be caused by various incidents such as a long planning horizon, a wide range of planning objects or distributed decision-making power. Instead of solving a comprehensive problem covering many different aspects by means of a monolithic model, hierarchical planning decomposes the overall problem into at least two less complex sub problems that are coordinated by well-defined interfaces.

The resulting planning levels can be modeled individually by adequate algorithms – either optimizing or heuristic – which are often taken from **operations research**. In the last decades of the 20th century, hierarchical planning methods have been applied especially to production planning problems and are reported to show great success. [8-10]

Typically, upper planning levels cover a longer planning horizon, work with more aggregated data and operate on a higher decision level than lower planning levels. The basic element of a hierarchical planning structure is a **two-level model**. The general workflow of a hierarchical planning approach consisting of two planning levels is given in Figure 2. [11]

The **top level** solves its aggregated planning problem considering the possible performance of the base level by means of an anticipated base model. It generates a solution for the overall system that is partially given as an instruction to the base level.

The **base level** solves its more detailed planning model under the restrictions given by the instructions obtained from the top level. The more slack these restrictions comprise; the bigger is the resulting solution space of the base model. Slack can be given in form of production capacities, scope for decision making or – especially relevant for IPS² – flexibility of the business model.

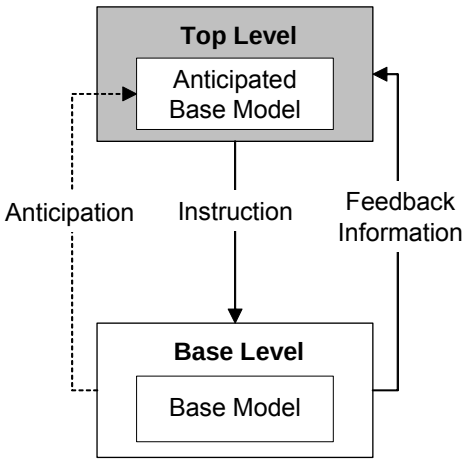

Figure 2: General workflow of hierarchical planning.

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After solving the base model, the base level reports its actual decisions and the resulting effects concerning the real-world problem to the top level. As the success and the monetary compensation of the top level depends on the results of the overall system and thus partially on the performance of the base level, the top level evaluates this feedback information in order to generate better instructions during the next run of the planning problem. [12]

A substantial advantage of hierarchical planning is its ability to respect existing **organizational structures**. Thus it obtains much more acceptance within the company than monolithic planning approaches. For these reasons, hierarchical planning shows a wide range of theoretical and practical applications.

3.2 Elements of hierarchical planning

The substantial principle of hierarchical planning is the combination of four **problem simplification strategies** that allow reducing the complexity of the overall planning problem to a manageable size. Theory of hierarchical planning identifies four basic elements that have to be coordinated adequately, see Figure 3: [10, 13]

Decomposition

Decomposition allows solving huge planning problems that are not manageable as a whole. A complex overall planning problem is decomposed into less complex sub problems. These are solved separately by adequate methods. In order to get a solution for the original problem, the results of all sub problems have to be coordinated by well-defined interfaces.

Hierarchy

After decomposition, the sub problems are assigned to hierarchical planning levels that are specialized on the solution of the respective problem. Thus a hierarchy of sub problems is established that coincides with the organizational structure of the enterprise. As a consequence, control mechanisms that are already established in the company may be applied for the coordination of planning levels.

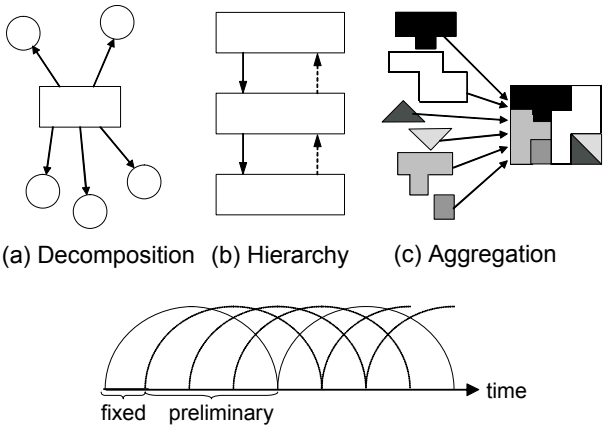

Figure 3: Basic elements of hierarchical planning.

Aggregation

Aggregation of products, production facilities and periods of time is used in order to simplify planning problems especially of upper planning levels. This helps to reduce the amount of data required, model complexity and uncertainties. The reduction of uncertainty results from the reduced variance of aggregated data. Overall, aggregation facilitates the solution of the resulting planning models.

Rolling Planning Horizon

The use of a rolling planning horizon on all planning levels allows deferring decisions for later periods to a point of time when better information is available. If the planning horizon comprises T periods, only the results for the first period are considered as fixed and are implemented. The results for the remaining T-1 periods are preliminary and subject to change if new information is supplied. In the next planning run, the plan for the second period is fixed and the horizon rolls to period T+1. Preliminary planning of later periods is necessary to prevent myopic plans that would be generated if the planning horizon were shortened to the fixed section.

Modeling a hierarchical planning approach, these four elements have to be adapted to the underlying real world problem and coordinated adequately. In combination, their ability to reduce problem complexity is even higher than in an isolated application.

Hierarchical planning has a wide scope of practical applications ranging from production planning and cost accounting to general principal agent relationships. [x5] [14] The following chapter will show how it may be applied to the planning of IPS².

4 HIERARCHICAL PLANNING FOR IPS²

4.1 Planning problems

Planning tasks concerning IPS² take place at different points of time, they cover different scopes, and respective decisions are taken by different agents. As it is neither possible nor sensible to make all decisions simultaneously, a problem-driven **decomposition** becomes necessary. Decisions can be assigned to two subsequent phases that have to be represented as hierarchical planning levels. It is obvious that the development phase has to become the top level whereas the operating phase shows the characteristics of the

subordinated base level. This **hierarchy** of planning levels is in accordance with the natural structure of the problem.

Development Phase

In IPS², product and service components are combined in order to create a solution to individual customer problems. The supplier strives to meet his customers' requests for individual business models each of with is a comprehensive and customized problem solution. Only if the customer becomes integrated into development, it is assured that all functionalities he desires are really incorporated so that the IPS² generates value for him.

On the other hand, the **configuration** of an IPS² from product and service modules (see section 2.2) is a decision that also has to generate a profit for the supplier. [15] He has to decide on the type and amount of his investment into the facility that will be delivered to the customer, on the kind of accompanying industrial services, and on the business model he is going to offer. These decisions are taken under uncertainty considering not only customer behavior during the operating phase, but also future technological development as well as various uncertainties of the environment.

In order to handle these uncertainties, the supplier can incorporate a high degree of **flexibility** into the IPS². Flexible resources, flexible products and the flexibility to change the business model during the operating phase if suitable assure a high degree of freedom to the supplier which allows him an appropriate reaction to changing request.

The decisions taken in the development phase are of **strategic relevance** for the economic success of the supplier. They are taken for a medium- or long-term planning horizon of several years. The focus of planning is on the **effectiveness** of the decisions taken. Effectiveness means doing do the right things in order to fulfill customer requirements. This requires double loop learning processes that challenge not only the fulfillment but also the purposes of an action. [16]

The characteristics of the chosen IPS² are passed as **instructions** to the operating phase.

Operating Phase

In the operating phase of an IPS² regular business operations that the supplier offers to the customer are taking place within the framework of the business model chosen in the development phase. The supplier has to take decisions on the quantities of products and services supplied in every single period as well as on the utilization of capacities allocated. As demand may vary, **process flexibility** is necessary on this operative planning level. The planning horizon for the operating phase is typically shorter than one year so that uncertainties are much smaller than in the development phase.

The focus of operative planning is on the **efficiency** of the provision processes for the services associated with the specific business model. Efficiency means to execute a given process with a minimum of inputs thus minimizing operating costs. So single-loop learning which pays attention to a quick and low-cost adjustment to changing demand and other imponderabilities is sufficient on this level.

Even if poor performance or unsatisfactory economic results indicate that the chosen business model should be changed, this decision is not within the range of the operative planning level. Rather a **feedback** to the strategic level is required.

4.2 Strategic Planning Level

The customer-oriented development and design of IPS² is the task that has to be performed on the strategic planning level. The **objective** of strategic planning is the maximization of the value added by the procurement of IPS². As it is necessary to provide specific IPS² for several customers, strategic planning not only has to allocate already existing capacity to competing purposes, but also has to decide about the enlargement or reduction of production and service capacities.

Strategic planning requires various **input data**: Customer requirements respectively anticipated demand for different products and services as well as anticipations for changes of business environment are sources of insecurity and have to be estimated as well as possible. Rather certain data is information about the production program of the company; that means the products and services actually provided. Furthermore, the anticipated performance of the base level is an important input for the top level.

The following **output data** result from strategic planning: Decisions on customer-specific variants of IPS² and the corresponding business models have to be made. These require specific investments into production and service facilities needed to provide the IPS². So the investment level for every period of the planning horizon is another output of the strategic planning model. Furthermore, decisions are necessary on the degree of strategic flexibility which allows changing the business model during operation of an IPS². This requires the assignment of a value to flexibility. Last but not least the operative planning level needs data such as revenue and cost parameters for the IPS² as a whole as well as for every single product or service component which have to be provided by strategic planning.

As it is not necessary to consider every detail of IPS² delivery and operation, strategic planning is performed on the basis of aggregated data. **Aggregation** is applied on production facilities on the input side as well as on business models on the output side.

Due to the high degree of uncertainty and fuzziness of input and output data of strategic planning, the top level has the property of an **ill-structured problem**. So it may not be modeled by an algorithmic method such as linear or convex programming. Instead, contract theory, flexible investment planning, and the real options approach seem suitable for this problem.

The **planning horizon** of strategic planning has to cover the whole IPS² life cycle which normally extends over several years. In order to keep complexity of the planning problem manageable, planning periods should not be shorter than a month. For periods in the far future an additional **aggregation** of time to quarters or even years might be favorable. Solving he problem with a rolling planning horizon helps to cope with the uncertainties addressed before.

4.3 Operative Planning Level

The focus of the operative planning level is on all activities that are necessary to operate an IPS² and adapt it continuously to changing demands and restrictions. Its **objective** may be formulated as maximizing the contribution margins of the IPS² delivered or as minimization of operating costs.

Input data of operative planning originate partially from the environment – such as actual customer demand, actions of competitors and global economic factors – whereas a substantial part is passed as instructions from the strategic planning level. Instructions comprise restrictions like the customer-specific business model for an IPS² or capacities assigned for its delivery and revenue and cost parameters of the product and service modules needed.

The result of the operative planning level are **output data** like the quantity of every product or service module delivered, the actual use of the IPS² specific and general capacities provided and the economic success of these activities.

As uncertainty of data on the operative planning level is much lower than on the strategic planning level, the problem at hand is **well-structured**. It may be modeled as a linear program for production and resource allocation planning. As standard software is available, an optimal solution is possible within reasonable computation time. Remaining uncertainty can be coped with by means of sensitivity analysis.

The **planning horizon** of operative planning is much shorter than for strategic planning. Usually, production and capacity allocation problems are solved for a horizon of one year which allows considering seasonality of demand. Planning periods should reflect operating days or shifts of the workforce. This framework is also suitable for operative planning of IPS². Similar to the strategic level, remote periods that due to the rolling planning horizon will be planned several times might be aggregated to weeks or decades without loss of solution quality.

The results of operative planning are detailed instructions which are given to the workforce for execution. If developments different from planning data arrive, the workforce has to react using **process flexibility** installed in its facilities.

4.4 Coordination of Planning Levels

Coordination of strategic and operative planning is achieved by information flowing from top to base level or vice versa. Three main flows of information can be identified that take place at different points of time (see Figure 4):

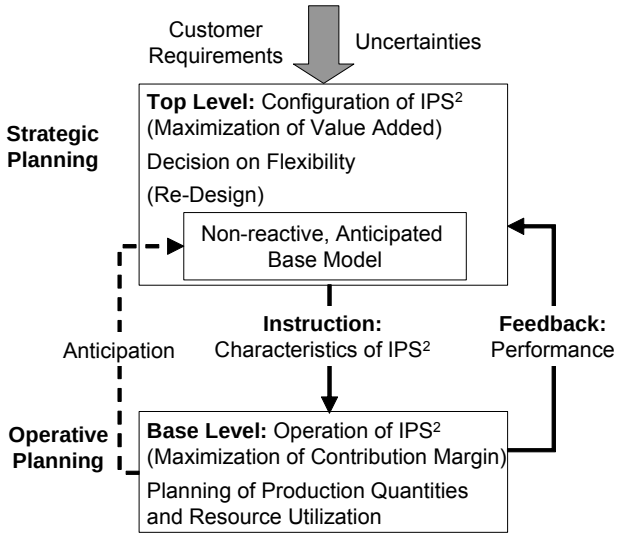

Figure 4: Coordination of strategic and operative planning.

- The first flow of information happens before the plans of both levels are definitely fixed. When the strategic planning level is solving its top model, it has to anticipate what results the operative planning level may achieve within the restrictions that correspond to a certain strategic plan. This **anticipation** is done by means of a non-reactive, anticipated base model which roughly calculates the possible results of the base level if the top level chooses a specific solution. This helps the strategic management choosing a policy that regards the qualified needs of both levels appropriately.
- The main connection between strategic and operative planning is the **instruction** that flows from top level to base level. It takes place when the top level has already made its decisions whereas the base level still has to perform its planning. As both levels from a hierarchical structure, the top level has the right to influence the actions of the base level either by direct commands or by indirect restrictions such as fixed amounts of workforce and machine capacity or fixed budgets. Concerning IPS², the characteristics of the IPS² offered to the various customers, especially the business model to be followed is the most important instruction.
- Last but not least there is a **feedback** flow of information taking place after plans have been implemented. The real performance of the operative planning level is reported to the strategic planning level. If results of the base level are insufficient and its management regards a change of the business model as adequate reaction, this information can also be given to the top level. The decision whether the business model is to be changed is definitely within the scope of the top level.

As both planning levels use a rolling planning horizon, experience and results of the expired planning period can be used for a dynamic learning process: Prognosis of insecure input data can be improved and planning methods can be defined in order to achieve better planning results.

5 SUMMARY AND FURTHER RESEARCH

The paper has proved that hierarchical planning is a suitable approach for the problems of developing and operating an IPS². Starting from general theory on hierarchical planning and using its four elements, a first formulation for the planning problems on the top level and the base level is given. Coordination of planning levels is achieved by instructions, feed-forward and feedback information.

The next step towards a hierarchical planning model for IPS² will comprise a more detailed specification of the planning models for both hierarchical levels. In order to calculate the economic benefit of an IPS², the operative planning on the base level should be related to a cost model. Here the approach of hybrid cost accounting could be used. [17] Furthermore, a practical application in form of a case study is desirable.

6 ACKNOWLEDGMENTS

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