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Design requirements for health care production control systems

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Keywords production control, health care, design requirements

Abstract. This paper addresses the issue of determining design requirements for production control in health care organizations, with a restriction to the internal production control of hospitals. Hospital management has limited possibilities to control hospital production, as hospital production processes are driven by medical specialists who, however, do not manage that process. We consider therefore the hospital as a virtual organization, consisting of a number of relatively independent businesses in a common framework. Each business unit functions as a focused factory for a range of more or less homogeneous products. Production control principles can be applied to each of these businesses, but not to the system as a whole. A number of elements from classical production control

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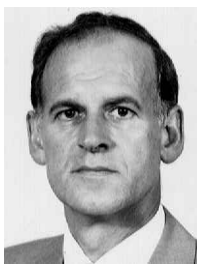

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theory can be also applied to health care, i.e. the use of decoupling points, the bottleneck-oriented approach, and the operational control between production and market. However, important factors that need to be considered in health production control are that often specifications on quality are not available at the start of the process, and that there is strong interaction between the patient and the process. Our conclusion is that a dedicated framework for approaching hospital production control is necessary. The specific characteristics of hospital care and its state of production control development are the main arguments for this dedicated framework.

1. Introduction

Production control or logistics can be defined as the coordination of supply, production and distribution processes in manufacturing systems to achieve a specific delivery flexibility and delivery reliability at minimum costs (Bertrand *et al.* 1990). Related objectives are to decrease the lead times, delivery times and costs, and to increase throughput, revenues and profit of the organization. Logistics-oriented manufacturing has contributed clearly and in many circumstances to improvements in performance for clients (delivery times, delivery reliability), as well as in terms of efficiency by a better balance between delivery performances and costs. See, e.g. Schonberger (1982), Wheelwright and Hayes (1985), and Stalk and Hout (1990).

Health care is confronted with similar challenges (e.g. Delesie 1998, Royston 1998), e.g.:

- increased complexity of processes by shorter lengths of stay of patients, a shift from inpatient treatment towards ambulatory treatment and day care, use of new technology and increased specialization;
- need for efficient utilization of resources and reduction of costs, on one hand because treatment is concentrated into a shorter time-space, and on the other hand because of the political pressure to control the national health care expenditures;
- increased pressure to improve the quality of services, amongst others by decreasing waiting lists and in-process waiting times;
- need to control workload of nursing staff and other personnel, because of the impacts on working conditions.

However, a hospital is not a manufacturing organization, but a special kind of service organization. The major differences with a manufacturing environment are listed below.

- Production control approaches in manufacturing organizations are focused on goods flow control. The core process of health care organizations is represented by flows of patients that are treated, while the flows of materials are secondary.
- In health care there is no perfect price-performance mechanism as is present in a market environment.
- Production control approaches presuppose complete and explicit specifications of end-products requirements and delivery requirements; in health care these are lacking.
- Health care organizations do not have a simple line of command structure, but are characterized by a delicate balance of power between different groups (management, medical specialists, nursing staff, paramedics), each of them having ideas about what should be targets for production performance.
- The key operators in the core process are highly trained professionals (medical specialists) who generate requests for service (orders) but also participate as key operators in delivering the service.
- Care is not a commodity that can be stocked; the hospital is a resource-oriented service organization.

Taking these differences into account, we can define production control in health care organizations—analogous to the definition of production control in an industrial setting—as: 'the design, planning, implementation and control of coordination mechanisms between patient flows and diagnostic and therapeutic activities in health service organizations to maximize output/throughput with available resources, taking into account different requirements for delivery flexibility (elective/appointment, semi-urgent, urgent) and acceptable standards for delivery reliability (waiting list, waiting-times) and acceptable medical outcomes' (Vissers 1994).

This paper addresses the issue of determining design requirements for production control in health care organizations. The design requirements specify the different control areas, the goals and the constraints for the production control system. We restrict ourselves to the hospital system as an example, and to its internal production control. The paper is structured as follows. Section 2 describes the hospital as an organization, using the concept of a virtual organization. Then in section 3 we will present general design principles for production control systems. Given these general design principles, in section 4 we describe the relevant characteristics of hospitals (markets, products and processes, and resources). Taking these specific hospital characteristics into account, in section 5 we discuss the issues related to the production control of hospitals. Section 6 concludes the paper with a summary of the results and an overview of the design requirements for health care production control.

2. The hospital as a virtual organization

The traditional hospital organization shows the structure of a professional bureaucracy with units built up around disciplines: nursing departments, paramedical departments, administrative department, etc. In The Netherlands—as is common in many health care systems—medical specialists, being contracted but not salaried by the hospital, are not integrated into this structure. Contrarily, specialists are responsible by law for the medical process of the patient and its outcome, and therefore play a crucial role in the realization of the objectives of the hospital organization. However, their interference with managerial matters is traditionally restricted to participation in advisory committees and via the advisory function of the medical staff body. More recent hospital organization structures show more integration by having the medical specialists taking up managerial positions and responsibilities in the management of newly formed units. The new units revolve usually around specialties. A unit can be a single specialty or a group of specialties, e.g. a surgical cluster and a non-surgical cluster. Another more patient-oriented example of clustering is an oncology unit, a maternity and child unit, etc.

In view of the position of the specialists, a hospital can be regarded as a virtual organization (van Aken *et al.* 1998). A virtual organization can be defined as an organizational network with distributed ownership whose partners share the same market (Davidow and Malone 1992). Virtual organizations can be temporary (project type) or durable (programme type) (van Aken *et al.* 1998); we consider the hospital as a durable virtual organization. The customer has the impression that products and services are provided by one and the same organization, but in fact many different autonomous organizations are operating behind the facade they share, and are involved in the delivery of services by the virtual organization. The different specialties within a hospital operate almost independently from one another, and after the patient has entered the hospital entrance and has used some shared facilities, he or she will visit the clinic of a single specialist.

Another characteristic of a virtual organization is the split between the strategic level, where company policies and strategic targets are set and investments required are determined, and the operational level, where within these boundaries complete freedom exists on how to organize operations. This applies to the hospital; however, the split in strategic level and operational level can not be extended to organizational positions, as medical specialists also strongly influence hospital strategy.

A third characteristic is the easiness of removing a partner from or adding a partner to the virtual organization, as the only criterion is the added value of the partner to the market performance of the virtual organization. In a hospital setting this materializes in adding a new specialty that will extend the services rendered to the population by the hospital as a whole.

A fourth characteristic of a virtual organization is the sharing of information. This applies as well as to information about the chains of operations to be performed in the virtual organization as to the communication between the operational and strategic levels.

Using the concept of a virtual organization, the following organizational dilemmas of a hospital can be put to the foreground.

- The hospital management's limited possibilities to control hospital production processes, versus the key position of the specialist.
- The control issue of matching demand and supply within the budget limits at aggregate hospital level, versus the control over the chain of operations of one of the many processes at patient level.
- The ill-defined ownership of the production process for a defined category of patients, versus the clearly defined responsibilities of the disciplines contributing services; specialists have a formal key role as they decide on the patient's transfer to a next stage in the process but they do not operationally manage the operations of that process.
- The sharing of information that is available about the chain of operations that form the patient process, and of information aggregated from operational level processes that is made available for strategic decision-making.
- The need to coordinate the different parts of the virtual organization, without being able to control all parts of the organization.

These organizational dilemmas should be kept in mind when considering the applicability of production control concepts in hospitals. In the next section, we will present a design framework for production control. The concepts used in this design approach will be used to discuss in more detail the processes in the hospital.

3. Principles of production control systems design

In this paper, we will follow the design framework for production control systems developed by Bertrand *et al.* (1990). This framework has been applied successfully to production control in a manufacturing environment. Their design principles state that for a proper design the following issues should be dealt with: coordination of demand and supply; goods flow control and produc-

tion unit control; aggregate and detailed control. In this section we will outline these issues in detail.

3.1. *Coordination of demand and supply*

Given the boundaries of the primary process considered, the demand for resources should be balanced with the supply of resources. Resources can be capacity, materials or services. This coordination of demand and supply takes place at two levels:

- the structural coordination: this refers to the setting of arrangements and conditions which allows for the operational coordination, including the target service level and resource utilization level;
- the operational coordination: this refers to the customer order acceptance, the ordering of materials and services, and the resource levels such that these are in balance.

Structural coordination is part of the tactical level of decision-making, and uses models which relate the performance or service that can be obtained at the operational level, the resources that can be made available, and the rules and regulations regarding the resource use resulting in costs and the decoupling points in the production process. In industry these latter include batch size rules, overtime rules, outsourcing rules and decoupling stocks. In a hospital setting, resource use regulations include, e.g. length of operating theatre sessions, and rules regarding the sharing of expensive resources like intensive care beds and wards. The resources made available, and the rules and regulations regarding their use put restrictions on the performance that can be realized; performance being defined as the amount of products that can be delivered, the flexibility and speed at which these products can be delivered, and the delivery reliability. In a hospital setting, the performance could be expressed as the amount of patients that can be treated, the flexibility and speed of access to the hospital, and the speed of treatment and the delivery reliability of the treatment. It will be clear that the quality of the operational control will also have an impact on the performance that is realized. However, operational control must work within the constraints given by the available resources and the resource use rules. Therefore, at the tactical level, a trade-off must be made between the available resources and resource use, on one hand, and the performance, on the other. As a result of this trade-off, resources will be available and resource use rules will be imposed which constrain the performance that can be obtained by the operational control.

3.2. *Goods flow versus production unit control*

Within the boundaries of the primary process, decoupling points can be distinguished in the flow of operations that are needed to satisfy demand. Decoupling points can be introduced in the flow for the following reasons:

- differences in batch sizes or combining of work-orders at different places in the flow;
- differences in specificity of material or activities (common materials upstream, more specific material downstream);
- differences in capacity flexibility; a highly loaded resource often is preceded and followed by a decoupling point, in order to protect the resource against variations in work supply (see also Goldratt 1984);
- reduction of demand uncertainty or manufacturing uncertainty; decoupling points are introduced at points in the flow where a large change in uncertainty occurs.

Decoupling points lead to inventories or work order backlogs which are controlled at the goods flow control (GFC) level. A production phase between two decoupling points is dealt with at the production unit (PU) level; i.e. local rules that apply within the boundaries of the production unit govern the progress of the orders. At the goods flow level, given the content of the decoupling points, work orders are released to the production units by goods flow control. Goods flow control aims at realizing the customer orders as agreed in the masterplan, taking into account the (in)flexibility and available resources in the production units. To support this coordination, each production unit is characterized by its operational characteristics. These state the output that can be provided by the PU, given certain conditions for available resources and load on the resources.

3.3. *Aggregate and detail control*

Aggregate control should be carefully distinguished from detailed control. Often materials and/or resources can be used for many different end products. This provides much flexibility in customer order acceptance, as many different combinations of customer orders can be dealt with by the same resources. However, in order to be able to use this flexibility, two things should be done.

- First, the aggregate products or product groups should be related to common materials or resources and their time-phased availability. This identifies

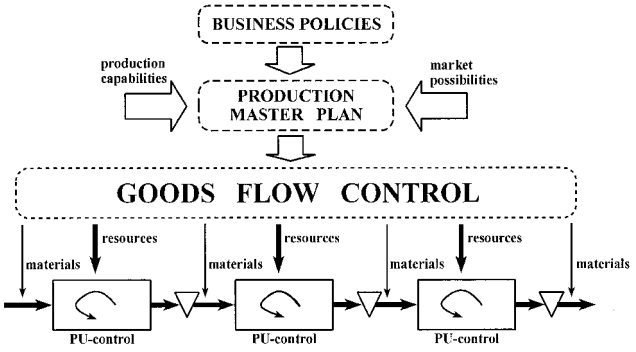

Figure 1. Principles of production control.

the flexibility that is available and that can be used in the demand–supply match.

- Second, for the aggregate products or product groups, the sales plans should be brought in agreement with the supply, and vice versa.

Detailed control, i.e. control which couples individual customer orders to work order resources, is necessary as soon as the material or resources are specified for that individual order. In general, many different types of commonality exist in production systems, and—more important—can be designed into a production system (e.g. the use of multifunctional work force and the principle of specificity postponement). Both at the goods flow control level and the production unit level, aggregate and detailed control should be distinguished, although in general more aggregate control will be found at the goods flow control level. Figure 1 illustrates the relationship between detailed planning at production unit level, goods flow control and aggregate planning.

The three principles do not provide direct guidelines for design, but identify the issues to be dealt with when designing a production control system, so they generate the questions to be answered. Now, from the description of the principles, it will be clear that its application assumes a well-defined production system: i.e. a homogeneous product range and a primary process that is geared to this product range. In other words, it assumes a 'focused factory'. If a company has a large variety of product ranges, a different control system should be designed for each product range. Often this leads to splitting up the organization into a number of business units, each dealing with one product range and having (in part) a private production system (business unit as focused factory). The organization as a whole, of course, facilitates the different business units, and the different business units have to follow the company policies. The design principles for production control outlined above apply to the business unit level and have no direct implication for company control. For instance, the planning of product ranges, and the financial and investment policies are outside the system boundaries of production control. However, the product planning does have an impact on the production control problem and should therefore be input to the design, but only as a conditioning factor, not as a decision variable.

The principles of production control discussed in this section raise the question to which extent the 'focused factory' concept applies to hospitals? Can we distinguish, within a hospital setting, product ranges with reasonable homogeneity in terms of underlying production processes and market characteristics in order to approach them as 'focused factory'? We will return to this in section 5, after we have described in more detail the characteristics of hospital care in the next section.

4. Business processes in hospitals

In the previous section we presented a design approach for production control. In this section we will discuss in more detail the characteristics of hospital processes in terms of the design approach. Therefore, we will describe the hospital market, the products offered by hospitals, the processes required for producing them, and the resources that are used for hospital production. The restriction of health care organizations to general hospitals is necessary to enable a full understanding of the mechanisms underlying operations management of health care provision. The complete spectrum of health care delivery, vertically from general practitioners and primary care to highly specialized care by university hospitals, and horizontally from acute care to psychiatric care, care for disabled and mentally handicapped, and care for elderly, would have been interesting too, of course, and could be a starting point for analogies with supply chain logistics in industries. However, this cannot be dealt with in one paper and therefore we concentrate on the general hospital as an important element in the medical care chain, offering the range of acute care services by surgical and non-surgical specialties.

4.1. *Market*

In most European health care settings, patients that require specialized care services normally get access to the hospital via the general practitioner (GP). Almost all people are registered at a practice list of a (group of) general practitioner(s) who deliver(s) services in the vicinity of people's homes. There is freedom to choose your own GP, but once chosen, people will normally stay with their GP and not shop around. The GP will be the first to be consulted once a patient has decided to

consult a physician. In case further investigations or specialized treatment is required, the GP will discuss the referral with the patient and decide normally for a referral to the nearest hospital that can offer the services required. Only in case of requirement of highly specialized services or a preference of the patient or the GP for a certain specialist will the GP refer the patient to a hospital that is farther away. This illustrates that the market of a hospital is first of all geographically defined by its catchment area. This is the area, measured by the number of inhabitants, that depends on a specific hospital for acute care services. As setting up a new hospital requires governmental permission and spreading of hospital facilities in a region is an important criterion, there is not much overlap in catchment areas. Only larger cities have overlapping catchment areas of hospitals and therefore experience more competition.

The second criterion for market segmentation is the degree of specialization required. Highly specialized services are only offered by larger or university hospitals. Referral to these services takes place via the specialist of the nearest general hospital or the GP.

The third criterion is the acuteness of the complaints of the patient. If a GP decides that the patient requires immediate attention by a specialist or in case of an accident, the patient is brought to the emergency department of the nearest hospital, provided a sufficient degree of specialization is available. Having been seen there, the patient normally is admitted as an inpatient for further treatment.

The main characteristics of the market for hospital services are, summarized:

- that it is a geographical market, organized by GPs and their registered patients, with minor overlaps and competition;
- that the degree of specialization required determines whether a patient has to travel further away from home;
- that the acuteness of the patient's complaints determines whether a patient is brought to an emergency department of a hospital.

Therefore, we can conclude that the hospital's market is, once established, reasonably stable.

4.2. *Products and processes*

How has the hospital organized its processes to meet the market demands? First of all, the hospital has organized its access: the emergency department for acute emergency cases; the outpatients department for patients that are referred for specialist consultation; the diagnostic centres that are used by general practitioners for diagnostic support services; and the inpatient wards for admitting patients that require overnight treatment.

However, the main characteristic of hospital products is that they are organized by specialty: internal medicine, cardiology, pulmonology, paediatrics, gynaecology, general surgery, orthopaedics, urology, etc. The physicians belonging to a specialty are specialized in treating complaints in a well-defined part of the human body; often there are even sub-specializations within a specialty, e.g. diabetics, enterology and oncology as specializations within internal medicine. This is in line with the referral system by GPs because the GP can define which specialty the patient should consult based on his first identification of the patient's complaint.

This referral procedure is further supported by the fact that specialty services are organized in a phase-wise manner. The patient first visits a specialist in an outpatient clinic to further investigate the complaint, define a first diagnosis and advise a treatment. This will be also reported to the referring GP, which creates the opportunity to communicate between GP and specialist about the patient's treatment. Depending on the outcome of the investigations, the specialist can advise the patient to return to the GP for follow-up, treat the patient in an outpatient setting by therapies (drugs, etc.) or by surgical procedure (day surgery), or admit the patient for inpatient treatment at a ward. Sometimes GPs and a specialty have developed guidelines on referral and back-referral, and on communications. The phase-wise system allows the GP to send in a patient to a specialty with only an initial idea on the cause of the patient's complaint. The investigations by the specialist can confirm this idea or reject it. If the treatment is simple, the GP can continue the treatment; otherwise the specialist can take over the treatment of the patient.

A considerable number of outpatients are treated by a specialist for a complaint on a tentative basis without a diagnosis; this phenomenon occurs more in the case of non-surgical specialties; these patients often leave the system without a definite diagnosis. One way to overcome this problem for the specialist is to consult other specialties in the same hospital or refer the patient to a hospital with more highly specialized services. Still, however, this system of consultation is a continuation of a monodisciplinary organization of hospital services.

A recent development is that, within the hospital, multidisplinary teams or even centres are being formed around multi-causal health care problems of patients. This can lead, e.g. to an oncology department in which general medicine physicians, surgeons and radiotherapists collaborate in the treatment of oncology patients. On a smaller scale, centres are established to treat well-defined categories of patients; examples are backbone problems, varicose veins problems or a stroke unit.

The range of products offered via monodisciplinary or multidisciplinary teams can total more than 1000 items, measured in terms of medical diagnoses based on the international classification of diseases (ICDC). The concept of 'hospital products' still requires further thought. Fetter (1983) has developed the DRG system (diagnostic related groups) to classify all diagnoses into groups of diagnoses that are recognizable for physicians and homogeneous in terms of use of resources. He arrived at 467 DRGs to describe the hospital's inpatient output. Lines of development include an extension by using ambulatory visit groups (AVGs) for classifying ambulatory care products (see Fetter and Averill 1984), and a refinement of DRGs by also taking into account the stage of development of the disease with the patient (see also Fetter and Freeman 1986). Another line of development is a limitation of the number of hospital products, defined as combinations of diagnosis and treatment, to a manageable set (Baas 1996). Whatever system for classification is chosen (diagnosis, DRG and its refinement, AVGs or diagnosis–treatment combinations, see also Ploman 1985), the products within a single product group show rather high variability and low homogeneity. The reasons for this are that there are many sources of variation, e.g. interdoctor variation within a specialty and interpractice variation of a specialty between hospitals. But also the variability of the services produced by a single doctor within a product group is rather high because of the fact that the eventual service delivered is always the outcome of the interaction between the patient and the doctor.

The main characteristics of hospital products therefore are:

- there is no single way of classifying hospital products, and even the concept of hospital product is not yet fully developed;
- whatever classification system is used, the number of different hospital products is considerable;
- within product groups, the process variability is high and the homogeneity low due to interdoctor and interpractice variation, and interpatient variation at the level of a single specialist's practice.

The discussion on hospital products up to now also offered some information on the processes leading to them. However, the concept of a hospital care process requires some further attention. Of course, a hospital process can be described, like any production process leading to a service or product, as a chain of operations, in this case performed by the specialist, nurse, paramedic, etc.

However, there are some process characteristics that have a strong impact on the predictability of the outcomes and resource use of hospital care processes. These characteristics are as follows.

- Treatments for well-defined complaints with almost 100% certainty about the processes required and the outcome (e.g. a bone fracture) should be distinguished from treatments for ill-defined complaints with no routine treatment path available and no certainty about results. We call these the routine and non-routine processes.
- For routine processes it is possible to define a treatment path, often based on a clinical guideline or protocol, that defines the different operations in the process and their timing. Still the variability in resource use for these routine processes can be quite high due to practice variations, different modes of treatment, etc. but also due to the interaction with the patient. Nevertheless, process patterns can be recognized.
- For non-routine processes, the specialist will proceed in a step-by-step way, checking the patient's reaction on a treatment and deciding on the next step from there. There is no guarantee on the outcome, and there is no in advance lay-out of the the patient will follow. Naturally, the predictability of resource use is much lower here than with routine processes.

Of course, these are the extremes on a continuous scale; there is much variation between specialties and within a specialty. However, the variation between specialties is dominant. For a surgical specialty with many protocol patients as orthopaedics, the routine may be almost 100%, but for a non-surgical specialty as internal medicine it can be less than 50%.

4.3. *Resources*

The most important resources of the hospital to produce its services are: staff (nursing, medical and paramedical), beds, operating theatres and diagnostic facilities. On an overall level, the total amount of resources is (in NL) limited by the hospital budget that is determined in the annual negotiations with health care insurance companies. The number of beds (including specialized beds for intensive care, etc.), range of specialties and number of specialists within a specialty are (in NL) controlled by governmental agencies to limit health care expenditures and to guide the spreading of hospital facilities.

Diagnostic facilities, e.g. pathology and X-ray, are shared between specialties. Patients are referred to these facilities from outpatient clinics. The workload of these diagnostic departments depends heavily on the distribution of referrals from these clinics over the days of the week, as many patients are investigated without an appointment and need to return with the results to the

specialist's clinic. There is a trend to integrate organ examination departments, e.g. ECG and pulmonology tests within the clinic organization of the supervising specialty, which makes these departments less shared than others.

Due to the budget pressure, there is a strong focus on efficient use of resources. Many hospitals have to operate on almost 90% bed occupancy level, which is considered as a maximum target without running into admission stops and specialists by-passing the planning by labelling all admissions as urgent. Operating theatres, being a very expensive resource, run at about 85–90% utilization of allocated time.

Changes in timetables for theatres and the outpatient department are difficult to handle because specialist-time as a resource is shared between the different workstations in the hospital: wards, theatres, outpatient departments, etc.

The characteristics of the resources used for hospital production are as follows (see also Vissers 1994).

- Availability and utilization level are predetermined and reasonably fixed.
- There are many dependencies between the use of resources, concurrently (shared resources) as well as consecutively (knock-on effects).
- It is difficult to isolate resources in time for dedicated use by a specified product group, as those resources are also used for other product groups.
- The multi-functional character of specialists (operations, clinics, examinations, ward rounds) in combination with his dominant position makes the specialist the leading resource in the process of allocating resources.

5. Applying the production control design principles to hospitals

In this section we will discuss the applicability of the design principles of section 3 to hospitals having the organizational and business process characteristics as presented in sections 2 and 4.

5.1. *Defining business units*

The first design task is to identify a number of product groups that are homogeneous in terms of underlying production processes and market performance. Regarding production processes, it is important that they use the same constellation of resources; the amount of resources used is not so important (which distinguishes a production control approach from an economic approach with iso-resource groups, e.g. DRGs) as the type and combination of resources required. This applies to categories of patients, e.g. oncology, stroke, diabetics, psychiatry and emergency. The categories should fulfil the following requirements:

- there should be a clear relationship with the resources required;
- they should be large enough in numbers of patients to allow allocation of dedicated resources;
- it should be clear in advance what level of specialization is required.

Such categories of patients form a product–market combination for which separate 'business units' can be defined within the general hospital infrastructure. To each of these units it is possible to apply the design principles for production control systems presented in section 3. We may expect large differences between business units with respect to resources needed, patient's length of stay, interactions between patients and personnel, etc. Forming business units per patient category allows for the focused application of the resources to each specific patient group, which can be expected to lead to more efficiency and a better quality for each category. However, this leaves us with the question what to do with the leftover patients that do not fulfil the above requirements. These will probably still constitute about 20% of total hospital input. One solution would be to define within each specialty a product group 'variable', which includes all other patient processes within the specialty that are not part of the previously defined product groups. Another solution would be to consider this 'rest' group as one business unit, which also can be run as a focused factory, this time focusing its organization on variety in processes. We should stress here that merely a splitting up of the hospital organization into business units revolving around specialties does not necessarily lead to focused factories; the business unit concept is then used as an organizational tool to decentralize managerial decision-making. If the splitting up into business units is not based on thorough understanding of underlying patient processes and market requirements, it will not lead to better controllability. The same complex control problems will emerge, but now on a smaller scale and in manifold, and this will create the additional problem of coordination between the units. Also we should point out that it is not always necessary to create physically separate units in order to form business units. Of course, if the scale of the business unit is large enough to allow a physical concentration of the resources required for the units' output, this should be done. But also when the scale does not allow for a physically separate unit, one can

create a focused factory by fixed time-phased allocation of the shared resources to the different business units (Vissers 1994).

5.2. *Defining decoupling points*

The second design task is to define the decoupling points in the patient flows per product group. Examples of decoupling points used in current hospital systems are the split between urgent admissions versus elective admissions (different requirements for capacity flexibility), and the split between outpatient care and inpatient care (different requirements of resources). Urgent admissions are dealt with by creating overcapacity (emergency department, emergency beds, etc.), while elective admissions fall under a planning regime. Decoupling points are needed when at different sides of the decoupling point, different planning regimes are used. Decoupling points lead to waiting lists, e.g. the waiting list for access as outpatient and the waiting list for admission as inpatient.

Another example of a decoupling point that is not used yet to its fullest potential is the split between diagnostic phase and treatment phase (differences in uncertainty). The differentiation between diagnostic phase and treatment phase does not necessarily coincide with the split between outpatient care and inpatient care. The concept should rather be applied on a gliding scale. As long as the diagnosis is not yet set (and the specialist is searching for a diagnosis by considering and investigating different options), there is much more uncertainty involved than in the treatment phase, once the diagnosis is set. Note that in this example the highest variability is upstream, and not downstream as is common in manufacturing settings. A treatment phase can, however, start in the outpatient care setting and does not always require an admission as inpatient.

5.3. *Patient flow and resource control*

The third design task is to establish for each product group control mechanisms for controlling the resource availability and the patient flow. In a hospital, shared resources should be distinguished from dedicated resources. Shared resources are used by more than one product group mainly because they are quite expensive and the resource use should be high. Shared resources can again be distinguished in leading resources and non-leading resources. A leading resource, shared by different specialties, requires a high-capacity utilization and is inflexible. Examples are IC beds and operating theatres. A non-leading resource does not require high-capacity utilization, or has capacity flexibility. Leading shared resources create dependency between the product groups. In order to enable a good planning of the patient flow, the time-phased resource availability of a shared resource for each product group should be known in advance. Therefore, at the hospital level all the patient flows needing the leading shared resources have to be added up in order to determine the total resource requirements, and next, the available resource has to be allocated to the product groups. Hospitals have difficulties with applying this design phase. The reasons for this are as follows.

- Many patient processes can only vaguely be described and their resource requirements are difficult to establish; therefore its better to aggregate these flows at the level of a specialty and determine their average resource requirements at an aggregate level.
- Resources are often allocated in a fixed way because of historical reasons, and not updated on a regular basis; some hospitals have developed procedures to update their allocations based on annual evaluation of developments in the number of patients and the utilization of resources; even in these cases hospitals are not yet capable of handling the different resource allocations in one integral capacity plan to take care of the many interactions between resources.
- Hospitals do not have a coordinating body that would be able to release capacity allocation plans and production schedules that are checked on regulations for optimal use of resources; in order to handle this coordination in the virtual hospital organization alternative ways should be followed.

Given the many dependencies between hospital resources, it is very important to handle the requirements for coordination between resources in the procedure for allocating resources (Vissers 1994). Requirements for coordination of capacity allocations are as follows.

- Coordination of the allocations of 'leading' resources to specialties sharing the same resource (capacity load levelling per 'leading' resource department).
- Coordination of the resource impacts for 'following' resource departments that are shared by specialties but often not allocated to specialties (e.g. X-ray).
- Coordination of the allocations of different resources to one specialty (capacity load levelling per specialty).
- Coordination of specialist capacity within a specialty (specialty planning restrictions).

Ignoring these coordination requirements may result in avoidable capacity loss, i.e. a poor performance in

handling the patient flow (avoidable waiting times, high variation in waiting times, avoidable repeat of activities).

Controlling the patient flow for each product group, given the available resources and the activities required in the diagnosis and treatment phases, requires knowledge of the urgencies of the patients in each of these phases, the resource requirement by the patients and the resource availability, including the resource flexibility. Product groups may exist which show high predictability of patient arrivals and treatments, and low need for immediate admission. For such a product group, a rather fixed efficient 'production plan' could be set up; arriving patients could be assigned to a 'slot' in the production plan and would then flow through the process in a very predictable way. Other product groups may exist which show low predictability of patient arrivals and treatments required, and for which patients may arrive which show a very high urgency for admission. For such a product group, patient flow control should allow for a quick response to the emerging needs in the patient's treatment plans; e.g. priorities may change regularly, and all kinds of resource flexibility that should be available.

Also, for different product groups, different performance requirements may be used, e.g. differences in the weight given to efficiency, throughput time, patient interaction, etc.

Our design principles show that patient flow control can only be developed if first product groups and business units have been formed. In current hospital practice, however, the control of patient flows is still an area that needs to be developed further. Up to now, patient planning systems are limited to the domain of a single unit, e.g. the operating theatres department, and patient flow-oriented planning systems, e.g. integral appointment scheduling (outpatient visits and examinations at medical service departments) or integral admission planning (admission, bed availability, operating theatre scheduling and nursing workload planning), are still underway.

The absence of business units based on product groups also explains partly why current hospital production control is not yet process based, but rather focusing on intermediate output. A production control based on processes would require well-defined processes, predictable resource requirements and delivery specifications. Many specialists might deny that this is possible and point at the high variability of operations. This is true, but this fact may also be used as a cover for not having to accept guidelines and protocols to defend medical autonomy. As there is low acceptance of considering processes in terms of a chain of operations, there is also hardly any mechanism developed for controlling these processes. As there are hardly any delivery specifications defined in advance, there are also no checks possible. Therefore, up to now the focus in hospital production is on day-to-day operations: how many beds are available today; has the test result for Mrs X arrived yet; next appointment in 2 weeks, etc. Thus, the focus is on separate intermediate outputs (outpatient visit, examination, test, admission, operation, etc.) without attention for the total process of the individual patients. Combined with the budget pressure, this also explains why the focus in production control is mainly on the efficient utilization of the resources, as this is the one 'shared value' for all specialties.

6. Conclusions

In this paper we have considered the hospital from a production control perspective, and we have investigated the relevance of current production control design principles and production control concepts developed in industry for a health care setting? The aim has been to identify elements of these principles and concepts that can readily be applied in a hospital setting, the conditions for their applicability and the adaptations needed for a hospital setting.

In section 2 we investigated the hospital organization from a business point of view. We concluded that hospital management has limited possibilities to control hospital production, as hospital production processes are driven by medical specialists who, however, do not manage that process. Therefore, we need to consider the hospital as a virtual organization, consisting of a number of relatively independent businesses in a common framework. Production control principles can be applied to each of the independent businesses, but not to the system as a whole.

Next, in section 3 we discussed design principles for production control systems. We distinguished decision functions related to the coordination between production and demand, the goods flow control and the production unit control, the control of aggregate flows and detailed control.

Given these principles, in section 4 we analysed the characteristics of the business processes in hospitals from a production control point of view.

We characterized the market for hospital care as relatively stable and fixed. The position of the hospital on the market is determined by its linkages to other health care organizations (vertically as well as horizontally); this forces the hospital into much more cooperation with other health care providers than an organization in a manufacturing setting. Moreover, the transmural definition of the process of the patient can have another scope than the process as defined by the hospital.

The elements of hospital products and hospital processes are not sufficiently worked out concepts yet to

allow for a control structure, we need to build on these concepts. The high variability in patient flows and resource requirements at detail level limits the possibilities for detailed control. Due to budget limits, hospital production control is focusing more on resource control and, due to the less-developed concepts of products and processes, on control on intermediate outputs. Budget pressure will not change, so the only way out is to invest in further definition of products and processes.

The highly interwoven resource structure is another argument for the current focus on resource control, and in the current situation limits the possibilities to control the patient flows. Therefore, final aggregation and aggregate flow and resource control is necessary at the total hospital level.

In section 5 we applied the design principles introduced in section 3 to the hospital processes described in section 4. We have seen that production control is only possible per patient group, managed by a focused business unit. Coordination of patient volumes and shared resources over business units must be done at the hospital level and is part of the strategic decision-making process as a virtual organization. Given the positioning of each of the business units within the hospital, for each business unit the function of coordination of demand and production, the control of patient flows and resources, and the control of units can be distinguished. At this level, the design principles are applicable and may lead to different control systems for different patient groups, e.g. using different decoupling points, waiting list management techniques, urgency policies and resource allocation strategies.

Important factors that need to be considered in health production control are that often specifications on quality are not available at the start of the process, and that there is strong interaction between the patient and the process. The patient can also influence the process by choosing position and bringing in control options that are not yet considered. Each patient, therefore, represents his own control space which needs to be used to the fullest extent. At the overall hospital level, decisions are taken about product–market combinations that play no part in production control as such but are part of strategic planning. These decisions define the conditions for production control, to be able to implement them, however, the assumptions underlying these decisions should be realistic.

In summary, the main conclusion of this paper is that a dedicated framework for approaching hospital production control is necessary. The specific characteristics of hospital care and its state of production control development are the main arguments for this dedicated framework. The unclear definition of concepts as products and processes, in combination with the high variability in practice between specialists and the strong orientation on the medical profile of the patient, do not allow the straightforward application of the standard production control concepts. Nevertheless, elements of these approaches can be used, taking into account the conditions that go along.

Further requirements for a hospital production control framework, in addition to those mentioned above, are that the coordination required for matching demand and supply at the hospital level is taken care of, and that the aggregate levels of control should be developed well enough to allow for detailed patient flow control. In a separate paper we will elaborate a framework for hospital production control, built on these conclusions.

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