Value Creation and Resource Interface Knowledge
Applying knowledge to the resource interfaces that embed Holmen's newsprint and IKEA's Lack table

Enrico Baraldi
Department of Business Studies and STS Uppsala, Uppsala University
Sweden
enrico.baraldi@fek.uu.se

Torkel Wedin
Stockholm School of Economics
torkel.wedin@hhs.se

Abstract

This paper discusses the interplay between *knowledge*, *resource interfaces* and *value* from an industrial network perspective. We conduct our analytical exercise on the networks that embed two very different resources, *Holmen's newsprint* and *IKEA table Lack*, but we chose to focus on the very same value-bearing feature for both resources, namely *low-weight*. We stress that the value of a resource derives from its combination with other resources in the network. Therefore, the interfaces between the involved resources play a key role both when this value is firstly embedded in the focal resource and when it is subsequently daily produced and utilized across the network. Accordingly, the knowledge concerning these resource interfaces is pivotal for value creation. We suggest a categorization of the knowledge behind value creation into four forms (generalized Vs specific and operational Vs conceptual). Our analysis of the two empirical cases discerns relevant differences in the ways knowledge is developed and applied in the newsprint and Lack networks. Such differences are related to the configuration of resource interfaces in the two networks. Knowledge is more dispersed in the newsprint network, where technology is also more complex, a wider range of competences intervene and many more indirect and hidden interfaces appear. By converse, the Lack network is more streamlined and one strong actor, IKEA, can more directly coordinate knowledge. Conflicts and barriers concerning knowledge development appear in both networks, but in the Lack network IKEA is in a position to quiet down conflicts, which however creates implicit barriers to developing knowledge and value towards certain directions.

Keywords: Knowledge, networks, value creation

1. Introduction: low weight, value and knowledge

The sofa table *Lack* is one of IKEA's core products, sold worldwide in more than 2.5 million pieces. Next to its low price, only €9.9, its most important feature is *low weight*, which is necessary to keep down transport costs accounting for 30% of its total costs. At the same time, Lack's low weight facilitates internal goods handling. Finally, a lighter Lack offers consumers a great advantage when they carry it home, and let us not forget that the chance that they buy a Lack table by impulse increases if it is light and easy to carry under their arms to IKEA cash lines. But low weight is a very valuable feature also in a completely different product, *newsprint*. Low grammage paper (i.e., thinner and hence lighter paper) increases the paper surface available in the huge rolls that printing houses purchase: as they pay by the roll, they can save money because the same roll contains more paper. Moreover, roll changes during printing are costly disruptions: having more paper per roll reduces changes and hence production costs. Low grammage paper has positive effects upstream too, allowing savings of raw materials: the same number of newspapers is printed using less pulp (because the paper is thinner). Finally, transport costs to final users decrease for each newspaper.

We have identified above an important feature, low weight (or low grammage), that provides a series of important values to numerous actors involved in using either a piece of furniture or newsprint paper. Our straightforward description of this feature and of its various uses hides however what goes on behind the curtain: for instance, low weight was built into Lack since its launch in 1981, by applying to tabletops "board-on-frame", a technology allowing resistant surfaces that are almost empty inside. However, it was not possible back then to apply this technology to the table's legs, which were left full inside and therefore heavier. A lot of new knowledge had to be developed in order to achieve empty legs, almost 15 years later. Similarly, the reduction of newsprint grammage results from a process of slow but continuous improvement that involves paper machines suppliers and paper/pulp producers: these actors face on the shop floor specific problems to which they apply their knowledge on a rather continuous basis. We can be sure that both for the table Lack and for newsprint the reduction of weight – that is, *the creation of an important value* – was not painless or automatic, but saw the confrontation, combination and re-combination of several resources, which required the development and application of diverse types of knowledge.

Considering the above processes of value creation, a first important question is "how is a focal value-bearing feature *embedded or built in* a product in the first place?" A second important question is then "how is this value *daily produced and utilized*?" A third key question is "what forms of *knowledge* intervene in the process and how do they behave in building in, producing and utilizing the focal value-bearing feature?" We can already at this early stage be sure about one essential characteristic of these processes: they involve several actors and firms. Therefore, we set in this paper for an investigation of complex business networks where value is created, produced and utilized.

The two first questions above help tackle the third one, which addresses the contribution intended for this paper: our purpose is in fact to discuss *how knowledge is developed and applied* in the creation of value around a specific resource in a business network context. The creation of economic value is a classic topic in all economic disciplines. However, the sources of value creation differ depending on the chosen perspective. In this paper we rely on the industrial network perspective (Håkansson, 1982) and stress how economically relevant values emerges from networks of interacting resources (Wedin, 2001, Håkansson & Waluszewski, 2002, and Baraldi, 2003). In other words, our starting point is that the value of a resource emerges from its interaction with a network of resources that embed it. More precisely, this value springs from a complex web of resource *interfaces* that have both a technical and a social dimension (Håkansson & Waluszewski, 2002: 190-200, and Baraldi, 2003: 17-19). We see resource interfaces firstly as sources of value, but secondly also as tools that can be handled for creating value. Thus, we will use our empirical material to show how resources are combined and their interfaces handled in order to create economic value. Achieving such a goal implies accordingly that knowledge about resource combinations and interfaces becomes central: since combining resources and handling their interfaces is crucial for the creation of value, we focus upon the *knowledge concerning resource interfaces*.

To discuss knowledge development and application in value creation, we chose two quite different focal resources: *newsprint* and the *table Lack*. However, we chose to focus on the same value-bearing feature, low weight, for both products. The paper is organized as follows. First we present a theoretical discussion about the sources of value creation where we highlight the issue of knowledge about resource interfaces. Then, the method and the two cases employed are presented. Next, we analyze and discuss the two cases based on our theoretical framework. We finally suggest managerial implications and further research.

2. Theory: value, resource interfaces and knowledge

This paper relies on two key assumptions: (1) that value creation depends on the interfaces between resources, and (2) that combining resources and handling interfaces requires certain types and levels of knowledge concerning resource interfaces (see section 2.3). The three key concepts of *value*, *resource interfaces* and *knowledge* interplay in a “value creation process”, according to the model displayed in figure 1.

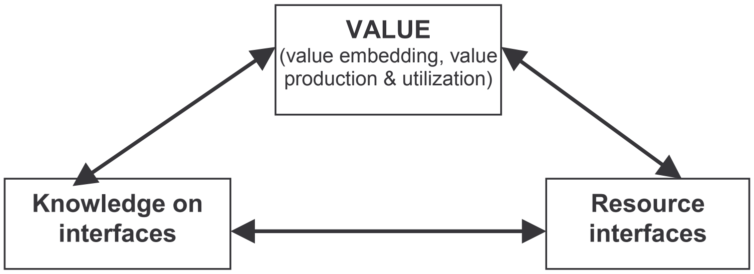

Figure 1: A model of the value creation process

Value can be regarded as the outcome of the value creation process. Resource *interfaces* are instead elements that can be acted upon in order to create value: interfaces are both the sources and the tools for value creation. Finally, *knowledge* concerning these interfaces is the precondition for the whole value creation process. Applying the model of figure 1 in these terms sounds rather linear, but it is a good start to understand the value creation process. The complexity increases if one recognizes that the three key elements *affect each other* (the arrows are indeed double headed): for instance, the identified and heaviest resource interfaces push for deepening knowledge about them and create lock-in learning (Arthur, 1988). However, our main tenet is that *knowledge by itself does not produce value, but must be applied to some specific resource interfaces*. For simplicity, our theory review focuses on each element per se, starting now from the outcome (value), moving through the intermediate element (interfaces) and concluding with the precondition (knowledge concerning interfaces).

2.1 The value of resources

Relying on the notion of resource heterogeneity (Penrose, 1959), we stress that the value of a resource does not reside in the resource itself, but depends on how a resource is combined with other resources (Ibid: 25, 74-75). It is not simply a matter that the specific *features* of a resource become more or less valuable only when confronted or put together with other resources, but resources even *shape* each other’s features during long-term interaction processes (Håkansson & Waluszewski, 2002). Put differently, the value of a focal resource emerges from the network of other resources that embed it (Ibid). It goes along with our relativistic theory of value that a resource must be valuable *for someone* or in relation to *something else* and for a particular purpose, that is, nothing could ever be valuable in a vacuum. These theoretical tenets imply that the creation of value is necessarily an interactive process and that value is always *idiosyncratic* and thus highly context specific.

Next to the interactive and relativistic nature of value pointed above, another key aspect of value is its *multidimensionality*, that is, there is not one single value but a multiplicity of values included in the very same resource. A resource always includes both physical (technical) and social features that can potentially deliver value to someone. Then, at a more fine-grained level, the value of a resource can be broken down, or decomposed, into several dimensions or value-bearing features. The value of a product can be for instance decomposed into the following dimensions: costs, functions/performances, durability, health-friendliness, style etc. Whenever one breaks down the value of a resource, one can reveal a *web of values* built into this resource by interactions with other resources that deliver specific value-bearing features. Whether the single value-bearing features are mutually additive (that is, increase the value of a focal resource) or not, depends on the context where these features are forged and utilized: some values such as low cost and high performance of a product may be mutually exclusive features because of resource constraints on the production side; however the low cost of a product may be the trigger that induces to use it in so high volumes to allow very high performances together with other complementary resources. In fact, economizing on a costly resource might need the development of features of another related resource. Thus, the attribution of value to resources is complicated by the fact that they are used together with other resources and that their several values interplay in highly complex ways.

The production and utilization of economically relevant values (i.e., features that affect cost and performance) happen both at a *physical* and a *social* level in a network. There is no automatism and determinism in the creation of values: even the most apparent physical features of a resource must be evaluated (=considered as valuable) by someone, if a resource is to be activated in utilization processes where its value is eventually "extracted". Moreover, the technical and social features of a resource are created and utilized in combination with other resources. We further stress therefore the idiosyncratic nature not only of the social, but also of the physical values of each resource: someone has to attribute value to the resource and this "(e-)valuation process" tend to be highly specific, depending on the contextual conditions where the resource is used and exchanged. Someone must find the resource valuable, either because of the way it is used technically with other resource, or because of the way it helps the firm to create "softer" commercial values, for instance to its customers.

Since the value of a resource depends on which other resources it is combined with (Penrose, 1959, Alchian & Demsetz, 1972, Håkansson 1987), the combination of resources is a key process. Organizations can undertake resource combinations either on a daily basis, indeed as a matter of routine (Moran & Ghoshal, 1999), or on special occasions, aiming to create new combinations and values. Routine resource combinations are the backbone of firms and do not require much reflection to be performed. On the contrary, new resource combinations might lead to initial problems, before they enter the existing resource base and the knowledge of how and why to combine resources has spread in the organization. Moreover, creating value from new resource combinations demands an embedding process that involves several actors, who need to *positively evaluate* the new combination. Routine resource combinations sustain daily value production and utilization, whereas new resource combinations allow value embedding in the first place. Both types of combinations happen constantly and can involve theoretically an infinite number of resources, but practically the actors in a network focus on a few resource combinations where they make investments to refine specific interfaces.

For any resource, the literature distinguishes between two types of value, a *use* value and an *exchange* value (Ramirez, 1999). Use value emerges at the technical level, from combining physical resources to perform transformation activities. Exchange value is instead created at the social level, from combining social resources to perform exchange activities (Johanson & Wedin, 2005). In value creation processes intervene both *technical* and *social* resources, the two main types of resources according to the framework that we present in the next section. A resource is seldom utilized in isolation and most activities are performed using several resources at the same time: it is in the interfaces with these other resources that the value of a single resource resides. Therefore, in the next section we take a closer look at resource interfaces and how they are related to value creation.

2.2 Resource interfaces and value

We aim here to define the concept of resource interface and to show its connection to the value of a resource. Our relativistic and multidimensional definition of value already switched the focus from a single resource to *combinations of* resources. Moreover, we know that resource combinations intervene both in the *original process of value creation*, whereby a certain value is for the first time embedded in a resource, and in *the daily processes of value production and utilization*, whereby a value is exploited on a routinely. We need however a more fine-grained theoretical concept and a more precise analytical tool to unravel the process by which value emerges from resource combinations. We need, in other words, a grammar and an enlarging lens that help us penetrate in the interstices between resources and their combinations. The theoretical concept is the notion of "resource interface" and the analytical tool is a resource classification framework that we can term "4Rs model" (see Wedin 2001, Baraldi & Bocconcelli, 2001, and Håkansson & Waluszewski, 2002). We start by reviewing the classification framework and its single resource items, moving then to the interactions between such items and concluding with the notion of resource interface.

Our analytical toolbox owes its name to the fact that it classifies resources into the four typologies of products, facilities, organizational units and relationships (Wedin 2001, Baraldi & Bocconcelli, 2001, and Håkansson & Waluszewski, 2002). Let us now briefly review each of these typologies (for a full description, see Wedin, 2001: 38-40, and Baraldi, 2003: 15-16):
a) products are any artefact exchanged between and within firms, including components, finished and semi-finished goods;
b) facilities are equipment, machinery, IT systems and tools utilized to produce or transform (physically or economically) products;
c) organizational units are resources of social type, whereas the two previous items are physical and technical. Organizational units are defined by a structure, a size and financial muscles, but also by more immaterial elements such as identity, competence and skills;
d) business relationships are social types of resources too. They are thicker forms of inter-firm interactions that emerge as firms progressively adapt to each other (Håkansson & Snehota, 1995). Business relationships are *quasi-organisations* that emerge as governance mode to coordinate inter-firm exchange (Richardson, 1972). As resources, relationships have a value on their own for the involved firms and can affect the value of other resources.

Units and relationships, that is, the social resources, are organizing elements for the physical ones, that is, products and facilities. The 4Rs model is not simply a categorization tool, because it also allows penetrating into the *interactions* between single resource items or groups of them. In fact, the focus should not be on the single resource items, but on the interplay between items. Resources "interact" with each other, in the sense that *they affect each other's features and values*. This "resource interaction" approach (see Håkansson & Waluszewski, 2002, and Baraldi, 2003: 14-15) allows observing how the value-bearing features of a resource emerge from its interplay with many others. Therefore, this is our main analytical toolbox in our discussion of the value creation process.

We can now turn to the intermediate element in the value creation process of figure 1, that is, resource interfaces. This is one of our central concepts deserving special attention. Resource interfaces (Håkansson & Waluszewski, 2002: 190-200) are the *contact points* that indicate how and how much two resources affect each other along technical (e.g., shapes, weights), economic (e.g., costs, revenues) and social (e.g., identities, preferences) dimensions. Two interfaces between a product and a facility are for instance (1) the time required to perform certain operations on that product and (2) the rate of defective products. Two interfaces between a facility and a relationship are for instance (1) the percentage of output dedicated to a specific customer and (2) the trust instilled in a customer by the operations of that facility.

Resource interfaces may partly depend on the "natural" features of resources, especially of physical ones, but they are always the result of human intervention in terms of identifying, expressing, measuring and forging them (Baraldi, 2003: 21-23). In a business network context, the interfaces between resources are shaped through long-term interaction processes involving several firms (Håkansson &Waluszewski: 190-200). For instance, the specific shape of a component can be the result of long-term adaptations to the production facilities of a specific customer. In other words, resource interfaces are "meeting places" where resources interplay and affect each other: physical "meetings" are typical in production process wherein resources are physically transformed and moulded together; but also social meetings involving units and relationships matter for the emergence of resource interfaces.

Resource interfaces can be categorized in several ways. A first distinction is based on the involved resource items: *technical* interfaces involve only physical resources (products and facilities); *organizational* interfaces involve only social resources (units and relationships); and mixed interfaces connect social and technical resources (e.g., a product and an organizational unit). A second distinction can be made depending on the *depth of interfaces* (Baraldi & Waluszewski, forthcoming): this distinction indicates how much two resources are mutually adapted, their reciprocal importance and the time and money invested in creating that interface. A third way to categorize interfaces is proposed by Håkansson & Waluszewski (2002: 196-197) depending on their *heaviness* (i.e., how difficult it would be to break them) and *variety* (i.e., how open-ended an interface is; a concept similar to "versatility", used by Håkansson 1987, & Holmen, 2001: 154-159). A fourth distinction is between standardised, negotiated, interacted and translation interfaces (Araujo et al., 1999). Finally, interfaces can be categorized into *direct* or *indirect*, depending on whether the effects between two resources are directly transmitted from a resource to the other or mediated by a third resource.

We need to stress precisely this point here: to understand how the value of a single resource emerges, one needs to unravel several *direct* and *indirect* interfaces that stretch across the whole network. In fact, value emerges not only alongside single resource-to-resource interfaces, but also from the complex web of indirect interfaces spread across the whole network. Since this paper investigates the value created around two focal products, it is pivotal to stress that the value of each product does not reside simply in the "Product-user" interface or in the "buyer-seller" interface. Instead, the value is distributed in all interfaces across the resource network. For example, as we shall see in the case illustration, the value of newsprint is created in the sorting of the wood, in the pulping process that produces specific strength features, which are then activated by printing units in the network around the paper producer. The several resources involved in value creation imply that several organizations take part, directly or indirectly, explicitly and implicitly, in the value creation process.

The above discussion suggests that resource interfaces are both the *underlying sources* of value, and that they are the target of managerial actions to create value. Differently put, resource interfaces are the *tools* that can be, at least partially, handled to create economic value. For this reason, we regard resource interfaces as the intermediate element in the value creation process of figure 1. However, it is not easy to handle resource interfaces, especially at a whole-network level: this is a demanding endeavor that requires certain kinds of knowledge, an issue to which the next section is dedicated.

2.3 The knowledge behind value creation

When the value of a resource is created and exploited, the involved actors need knowledge concerning *specific* resource interfaces, rather than general knowledge or knowledge about separate resource items. For example, a tire manufacturer must certainly consider the structure of the tire while developing a product. However, tires have a clear interface with the asphalt on which they will be used. Having knowledge of certain specific features of this asphalt, such as its ruggedness or hardness, induces the tire manufacturer to develop tires along such specific features as texture rigidity or thermal stability. Such knowledge is critical firstly for the *identification*, secondly for the *design* and thirdly for the *activation* of resource interfaces.

But the knowledge that intervenes in the value creation process is highly complex. Firms face not simply the knowledge coordination problem already identified by Hayek (1945: 519). It is not simply a matter of combining existing knowledge bits dispersed in the network to take care of the identified interfaces: knowledge is inherently *indeterminate*, in the sense that nobody knows in advance which knowledge is needed (Tsoukas, 1996: 22). It is especially hard to identify *indirect* interfaces and have clues on the knowledge necessary to handle them. Indirect interfaces are in fact sometimes hidden (Wedin, 2001) to most or all actors in a network, because they emerge from the fact that resources are part of a complex whole that entails infinite combination possibilities (Waluszewski, 1990: 203): thus, there are always some indirect resource interfaces, which have not yet been identified and for which some or all knowledge is missing. Indirect hidden interfaces entail for the involved actors a state of true ignorance (Kirzner, 1973) or radical uncertainty (Tsoukas, 1996: 22), whereby no one really knows what specific knowledge is needed to combine resources and handle resource interfaces. Because many potentially relevant and value-generating interfaces always escape from being identified (Baraldi, 2003: 21), *general* knowledge can only inspire the searching for such interfaces, whereas exploiting them requires *contextualizing* this knowledge.

The knowledge involved in value creation is complex both from a technical and a social point of view, because organizational interfaces (e.g., between two units) and mixed interfaces (e.g., between a product and a relationship) are often necessary to create value. But knowing of the existence of an interface and knowing the patterns of interfaces at network level is not enough for value creation, because this also requires knowledge on *how to handle* these interfaces. In particular, value is created by handling simultaneously three types of interfaces: (1) *technical* interfaces (involving products and facilities), which require a good deal of technical knowledge; (2) *organizational* interfaces (involving units and relationships), which require social knowledge (e.g., on how to motivate a supplier or on how to create a flexible organization); (3) *mixed* interfaces, which require knowing how to combine technical and social resources (e.g., how to utilize a facility given a supplier's delivery routine or how to induce a customer to adopt a new product).

The complexity of the knowledge relevant to handle resource interfaces reflects the issue of resource interaction and the relativity and multidimensionality of value that we stressed above. This epistemological complexity is compounded in business networks by their very social and inter-organizational nature: there are in fact several actors involved in any value creation and exploitation process and hence in any attempt to develop and apply the necessary knowledge. And not surprisingly, just as there are conflicting interests about resources, there are often also conflicting interests between firms in relation to knowledge. The very issue of which particular knowledge should be developed and how it should be applied can be ridden with conflicts that generate a sort of *knowledge politics* (Cyert & March, 1992). The problems to be solved to create value are likely to require combining the knowledge of several actors spread across the network. The path along which to develop this knowledge emerges from negotiations and bargaining between actors (Ibid). Knowledge-related conflicts are therefore not uncommon and a central issue in any value creation process in a business network. These socio-political aspects are a further issue that goes beyond the sheer epistemological complexity of knowledge coordination pointed by Hayek (1945). And the more actors involved the more risks for conflicts. Even if Håkansson, Havila & Pedersen (1999) point that the chances for learning increase when several relationships are well connected with each other, we suggest that this can also cause increased conflicts between the actors involved.

But despite the epistemological complexity of thinking at network level and despite the social complexity of knowledge politics, we still aim to stress here the importance of acting on single interfaces for the purpose of producing value. Therefore, we argue that it is essential to develop and apply knowledge concerning *specific* resource interfaces. This does not mean however simplifying the complexity of value creation, because we still rely on our basic tenets of resource heterogeneity, value relativism and multidimensionality. In fact, since value emerges from combining several resources, the knowledge of how a specific interface is related to other ones is pivotal. Moreover, if actors have some knowledge of the whole pattern of resource interfaces in the network, they are more likely to avoid decisions that might look adequate on a local level (for single actor or interface), but that appear less informed if the whole network pattern is taken into account.

Different forms of knowledge: types and levels of interface knowledge

The knowledge involved in value creation takes several forms, such as organizational skills, routines, scientific principles, and formalized models. These forms of knowledge can be categorized in different ways: for instance, tacit Vs explicit (Polanyi, 1967: 4), know-that Vs know-how (Ryle, 1949: 28), “know-what, know-why, know-who and know-how” (Lundvall & Johnson, 1994), or direct Vs indirect (Loasby, 1999: 51). For the purpose of our study we choose to distinguish between two levels and two types of knowledge concerning resources interfaces. The two types are *general* Vs *specific* interface knowledge and the two levels are knowledge about *outcomes* Vs knowledge about *causal relations* (Wedin, 2001: 218).

The *general* type of knowledge on an interface concerns the interaction between two resource items (e.g., tire and asphalt) at a context-independent level. The s*pecific* type of interface knowledge concerns instead the interaction between two specifically identified resource items within a particular context (e.g., a Michelin tire of “model XY” and the asphalt of South French roads[1]). Knowledge at the *outcomes* level concerns the existence of a relation between two variables and suggests how to obtain a certain outcome on one of them (e.g., to increase adherence to asphalt, the hardness of a tire must be reduced). However, this level of knowledge excludes the *reasons why* a resource combination produces a certain outcome, which is instead embraced by the other level of knowledge, about *causal relations* (e.g., hard tires have poor adherence because their texture does not create enough friction on the asphalt surface). Causal relations knowledge is very important because it helps to change resource combinations to improve their outcomes as well (e.g., the tire manufacturer can identify the chemical composition that creates the texture that provides the desired adherence).

Causal relations knowledge is of *conceptual* nature, whereas outcomes knowledge is more *operational*[2]. Ackoff (1996) uses the term “understanding” (Ibid: 29) for causal relations knowledge, while calling simply “knowledge, as contained in instructions” (Ibid: 28) the knowledge on outcomes.

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[1] A tire manufacturer needs general knowledge on the combination of tires and asphalts. But what the racing tires manufacturer really needs to create value for a Formula 1 team is the specific knowledge of how its newest tire model behaves in interaction with the asphalt of the Imola’s racing circuit in Italy, and in various racing conditions such as rainy, sunny and hot days.

[2] Nonaka & Takeuchi (1995: 71-72) view these two levels of knowledge as the result of two among four possible knowledge creation modes: conceptual knowledge emerges through *externalization* of tacit knowledge into explicit knowledge and is manifested by models, theories and formulas; operational knowledge emerges through *internalization* of explicit knowledge into tacit knowledge and is manifested by routines, know-how, experience.

Our distinction follows different criteria than those of the above authors: outcomes knowledge includes both know-what and know-how, whereas causal knowledge includes some know-what, but mostly know-why; outcomes knowledge can be both explicit (e.g., written rules, procedures, using manuals) and tacit (e.g., skills, capacities, organizational routines and structures, machinery, cultural norms), whereas causal relations knowledge is mostly explicit (formulas and calculations, formalized models, theories), but can also be *embodied* into certain highly automated machinery, namely IT systems and equipment steered by computer models, and into all mechanisms that apply automatically rigid and formal models (for instance, an accounting or a personnel reward system).

The two levels and the two types of knowledge can be combined into the matrix of figure 2. The conceptual knowledge of causal relations is a more advanced type of knowledge than simple outcome knowledge, but the former provides real value only when it is contextualized into specific interfaces (in the cells on the right hand side of the matrix).

		Types of interface knowledge	
		Generalized interface Knowledge	**Specific** interface Knowledge
Levels of knowledge	**Outcomes** knowledge	General and de-contextualized operational know-what and know-how	Interface-specific operational know-what and know-how
	Causal relations knowledge	General and de-contextualized understanding (conceptual know-why)	Interface-specific understanding (conceptual know-why)

Figure 2: Types and levels of interface knowledge found in networks
Source: Adapted from Wedin (2001: 218)

The matrix categorizes different forms of knowledge which are applied in the combination of resources in networks. The matrix decomposes the knowledge that intervenes either in *routine* or in *new* resource combinations, such as those attained respectively in production/exchange episodes or in product development. Every problem solving situation typically involves several resource combinations, some of which rely on *specific* interface knowledge and others rely on *generalized* knowledge. At the same time, the two levels of *operational* and *conceptual* knowledge are applied in different degrees: for some interfaces it is enough to know about the effects of a resource combination, but for some other critical interfaces it is necessary to know the causal relations in order to improve a resource combination. In the empirical accounts and analysis, we shall explicitly introduce the network and the interactions that envelop the knowledge forms behind value creation. Therefore we show how situated and embedded in the network knowledge development and application is. This exercise helps to identify how the network creates drivers and hindrances, possibilities and limits to knowledge development and hence to value creation.

3. Method: investigating value around furniture and paper

Our empirical material is grounded in two extensive case studies, each one entailing between 70 and 100 personal interviews conducted across the networks where each of the focal products is embedded. One case study concerns the production and utilization of newsprint in the whole network stretching from electricity production to printing and publishing (Wedin, 2001); while the other case study concerns the development and operations, from production to retailing, of IKEA’s table “Lack” (Baraldi, 2003). For the newsprint case, about 100 interviews were conducted in the period 1995-2001 at more than 40 organizations, each one affecting directly or indirectly the focal resource, newsprint. However, the investigation started from a focal organization, the paper producer Holmen Paper and its production unit Hallsta, located a few kilometres from Uppsala, Sweden. The Lack case relies instead on about 70 interviews, conducted in the period 2001-2003 at more than 20 organizations involved in the development and daily operations around the focal resource, Lack. As in the previous case, also this investigation started from a focal organization, IKEA of Sweden, the unit in charge of managing IKEA’s product range.

We chose to make use of these two case studies for several reasons: 1) the cases are very rich and fit our theoretical ambitions, because the empirical material was collected with the explicit goal to penetrate resource interactions stretching to a whole network; 2) we already knew that the different configurations of the networks around the two focal products would entail some relevant differences (which will be made evident in the empirical sections) in the process of knowledge development and application; 3) despite the differences in the types of focal products (a bedside table and newsprint), with their very different network contexts, we searched for some common denominators in the maze of resource interactions linked to value creation. We believe that by analytically comparing these two case studies it is possible to identify both common, general patterns and salient differences in the issue that we investigate.

From the extensive empirical material collected for these two large case studies we selected two value creation processes that we present and analyze in detail on the basis of the general model presented in figure 1. Therefore, within a general *double case study design*, we make use of an "embedded case" (Yin, 1989) or "multiple-level-of-analysis case" research design. This methodological approach is helpful especially when the research issue to be tackled is a complex one (Ibid), as in our investigation, and the approach has been fruitfully applied to tackle the complexities of industrial network (Easton, 1995: 480).

Each case starts by presenting the focal product and the network in which it is embedded. For each product we have selected *one* value-bearing feature, *low-weight*, which is seen as valuable by one or several actors in the network. The cases continue with an illustration of the process that led to the embedding of this feature in each product, showing the involved actors and resources. Then, we illustrate for each product the daily processes whereby the value-bearing feature is produced and utilized by one or several actors. We stress how this value emerges from the interaction with other resources and we penetrate into some of the specific interfaces involved in the selected value creation process. For each of these interfaces, we present the knowledge involved in the original value embedding, and in the daily value production and utilization processes. We show the kinds of knowledge developed and applied in both network contexts. However, we dedicate our analytical section to showing and discussing in detail the forms and dynamics of the knowledge involved the original value embedding and in the daily value production and utilization. In that section we also highlight the barriers or possibilities that the network context poses to developing and applying knowledge to resource interfaces. In this way we situate in a network of resources and actors the knowledge development and application that accompany value creation.

4. The Lack case: resource interfaces, knowledge, and low weight

IKEA is a giant in furniture retailing, with 65,000 employees and about 200 stores that sell for over €12 billion a range consisting of 12,000 product items. Today's impressive figures rest on the fact that for 60 years IKEA has aimed to produce furniture with a strong low-price focus. But in order to achieve this goal IKEA does not behave like a traditional retailer that simply "shops around" for available lowest-price solutions; IKEA is instead a *production-led* retailer that considers the resources involved in manufacturing and transportation, all the way from raw materials to customers' homes. A key ingredient in this strategy is close business relationships to suppliers and logistic partners that help IKEA maintain its low prices.

The Lack table well symbolizes this approach. The price of this bestseller, sold in 2.5 million pieces per year, has been stable for 23 years at €9.9! Since its launch in 1981, IKEA expected Lack to become a symbol for its surprisingly low prices, but with the constraint that Lack should cover all its costs. This obliged IKEA and its suppliers to carefully identify such costs and act on the resources that impacted on them. Since transportation accounted for about 30% of the total cost for such a low price product, IKEA and its partners had to find a technical solution that would reduce transport costs. *"We knew that weight was the main determinant of transport costs and our goal became therefore reducing the weight of Lack tables"*, as an IKEA product manager put it. The solution was found in the so called board-on-frame technology employed to produce inner doors: a frame of chipboard was filled with special honeycombed paper and covered by a thin sheet of HDF (high-density fiberboard). The result was a very light construction, because it was mostly empty inside, but one that was still highly resistant: therefore board-on-frame was applied to the production of Lack's tabletops.

For over a decade this low-weight solution was enough to keep down Lack's transport costs. However, there still were some parts of a Lack table that could not be low-weight, that is, "empty-inside", namely its legs. Legs posed special technical problems and board-on-frame could not be applied on them: their small surface, in relation to their height, impedes to fill them with honeycombed paper oriented perpendicularly to their surface, a requirement to obtain a solid surface. Even though lightness was seen as a very valuable feature for Lack's legs it was not easy to attain. Attempts were made with plastic legs: they were lighter than solid wood, but they posed great problems in coating because it was almost impossible to achieve color uniformity with tabletops. And customers reacted quite negatively to these "hybrids". In the early 1990s it was clear that a more long-term solution was necessary in order to extend the low-weight feature to Lack's legs – hopefully a solution based on the same "empty inside" concept as tabletops. It was at this point that IKEA explicitly asked its supplier Swedwood Poland, which for a few years had manufactured all Lack tables, to envisage a technical solution to build empty legs. This request was at the origin of an important development and value-embedding episode that we now describe in detail.

4.1 Creating low-weight value by developing Lack's empty legs

Swedwood had not all knowledge necessary to solve the complex technical problems of empty leg, but it had a close relationship to Wicoma, a mechanical engineering shop located just a few hundred meters away that for several decades had been repairing, maintaining, tuning and further developing Swedwood's machines. It immediately appeared that no easy fix technical solution would allow obtaining empty legs: Swedwood's production facilities could not be easily modified to produce empty legs and a quite radical re-engineering of the leg construction appeared necessary. Therefore, given IKEA's strong interest in reducing the weight of Lack's legs and likely long-term engagement to this type of product, Swedwood accepted to embark on a development effort that aimed at engineering both a wholly new machine and the construction of Lack's legs, to have them really "empty inside".

However, not everything should be new in the solution leading to low-weight legs: *"We knew that introducing new materials than those we had for Lack's tabletops would increase costs and complexity. So we decided to use the very same materials, HDF and chipboards, also for Lack's legs"* as a technician at Swedwood notes. In fact, Swedwood had extensive experience of these two materials, even though in a different manufacturing application. In particular, Swedwood knew how to cut and glue together chipboards into frames and how to cut square surfaces of HDF as thin as 3 mm and how to glue them on the honeycombed paper-filled frames. However, this knowledge could only be used as a *starting point* in envisaging a solution for the construction of empty legs and, especially, for the new machine that should automate leg manufacturing. Instead, Swedwood and Wicoma had to work together to develop new knowledge: a new construction that both respected the same-material constraint and could be automated on a specialized, but not too expensive and high-tech machine.

Swedwood and Wicoma's technicians faced the problem of recombining HDF and chipboards (the only allowed materials) into a solution consuming as little material, and hence weight, as possible. A further constraint was that the re-combination of HDF and chipboards could be automated at relatively low costs. After several meetings around a drawing table technicians from Swedwood and Wicoma figured out how one could obtain stable and resistant legs starting that required as little material as possible. This solution relied on (1) a few squared chipboards to be placed about 20 cm apart from each other inside the leg and (2) a light and flexible HDF sheets to be literally bent and glued around the chipboards to hold them together and thereby creating the leg's external, vertical surface.

In parallel, Wicoma's mechanical engineering competence was essential to devise a unique and specialized machine capable to put together efficiently the above components, while performing key operations (e.g., carving and bending HDF sheets). Developing this leg line required penetrating complex engineering details about the technical functions, output capacity, speed and precision level. A small but essential detail is that Wicoma needed to know is that in order to have HDF sheets exactly stick to the chipboard's lateral surfaces, it was necessary to carve each HDF sheet along three lines. But even more than so the machine needed to be able to carve with great precision: (a) with the right carving depth (not too much that would break the sheet, nor too little that would make it impossible to bend the sheet) and, (b) with the right carving angles (to allow HDF to stick exactly to the corners of each chipboard). Finally the leg line should also glue and press to obtain a complete leg for Lack.

Wicoma had experience of such technical issues as basic operations, architectural design and key subsystems (e.g., engines). *"But the project was so specific that Wicoma had to develop the technical specifications together with us, because we were the only who really knew how the machine should perform on chipboards, HDF and glues"*, as stressed by a Swedwood technician. For instance, triangular tables need triangular legs: therefore the leg line needed to be able to fold HDF sheets with only two carvings around triangular chipboard inserts. Even if the leg line is considered today as a rather simple machine by Swedwood's technicians, it was essential to create and build into Lack value in terms of a further weight reduction.

In the above value embedding process, 8 resources played a key role: *empty legs* (where the low-weight feature physically resides); *HDF* (a main input to achieve low-weight); the *leg line* (the facility that mechanized manufacturing); *Wicoma*, *Swedwood* and *IKEA* (the three organizational units involved); and the business relationships *Wicoma/Swedwood* and *IKEA/Swedwood*. These 8 resources are presented on the network of figure 3.

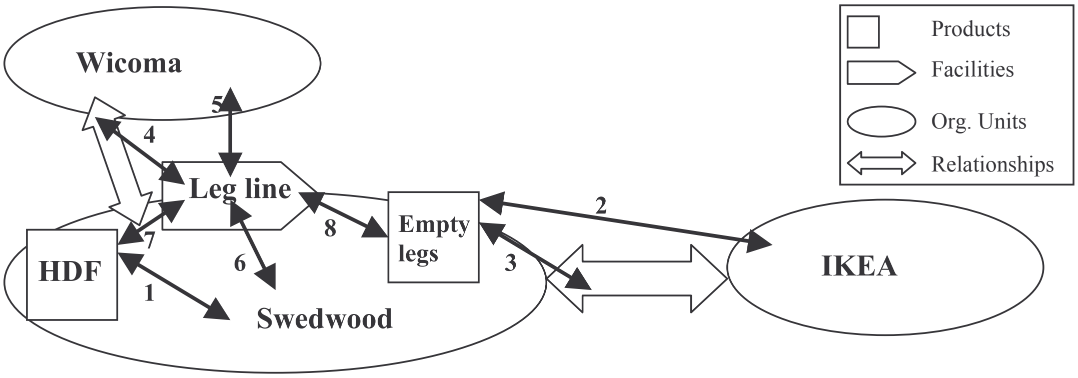

Figure 3: The resources involved in creating low-weight legs for Lack

Which were the interfaces among the above resources that were most important in building into Lack the value-bearing feature of low weight? The following ones played certainly a key role and are depicted by solid double-headed arrows numbered from 1 to 8 in figure 3. The numbers given to each interface also roughly indicate when they progressively appeared on the scene or were consolidated, giving a sense of the underlying process:

1) *Swedwood-HDF*: this is the oldest interface that pre-existed the idea and concretization of empty legs, but it is an important one because it "imposed" the constraint of using HDF, not only for its lightness and resistance features, but also for the costs associated with an eventual change of materials and for the extensive experience of this material held by Swedwood.

2) *IKEA-Empty legs*: this interface too pre-existed the concrete solution for empty legs, indeed it was the sparkle that initiated the whole technical development described above because of IKEA's generalized knowledge of the possibilities of obtaining some form of cost saving in transportation by reducing the weight of Lack's legs.

3) *Relationship IKEA/Swedwood-Empty leg*: this interface acted as a further motivator to induce Swedwood to embark on a costly development project, based on the knowledge of IKEA's long-term engagement in low-weight products and in this specific relationship.

4) *Relationship Wicoma/Swedwood-Leg line*: this interface partly pre-existed the empty leg solution and was the channel to involve a key partner both knowledgeable of Swedwood's manufacturing process and materials and willing to engage in a costly development effort. The technical specifications for the leg line were jointly shaped by Wicoma and Swedwood.

5) *Wicoma-Leg line*: when the solution started taking form, as a blueprint, this interface pushed the further concretization of the special manufacturing solution. Wicoma's mechanical engineering competence played a determinant role in this direction, especially for the "homework" that Wicoma had to do for devising the subsystems that would achieve the functionality needed by Swedwood and for putting them together into a functioning machine.

6) *Swedwood-Leg line*: this interface became more and more relevant as the machine took shape, a process to which Swedwood contributed its experience of woodworking and of how the leg line should fit in the whole manufacturing process for Lack. Not only technical issues, but also Swedwood's investment and cost calculations contributed to shaping the machine.

7) *HDF-Leg line*: this interface required a great deal of specific technical know-how in order to build into the leg line the capacity to transform a flat sheet of HDF into a tri-dimensional structure. For instance, the precision in carving HDF required detailed calculations and the engineering of cutting tools capable to cope with these stringent tolerances.

8) *Leg line-Empty legs*: this is finally the interface where the value-bearing feature of low-weight is physically coined into Lack, thanks to the specific quality of the operations that this machine can perform. Empty legs are the output from the leg line and close the circle in this process of value creation that had started with IKEA's whish to reduce its transportation costs.

From this moment on, empty legs become a relatively hidden element in a lower weight Lack that can be utilized by other actors in the network, as we shall see in the next section. These value embedding/creation efforts were sustained by very *variegated* knowledge: IKEA's cost and commercial calculation, its market experience that consumers do not like plastic legs with poor color results; Swedwood's knowledge of materials and manufacturing and of IKEA's needs and goals, including the fact that the required investment in the new machine will be corresponded by IKEA's long-term purchases of empty legs and Lack; Wicoma's engineering knowledge and experience with Swedwood's manufacturing processes and materials.

4.2 Daily producing and utilizing the low-weight inside Lack's empty legs

Once the specific empty leg solution was identified, it was relatively easy to implement it at Swedwood's plants. Soon this supplier started daily producing low-weight legs that, packed with Lack's low-weight tabletops, could now be delivered allover the world. We can now review the processes respectively of daily production and of daily utilization of the valuable feature of low weight. In doing this we have to include several other actors, resource and interfaces that lie farther and farther away from those that originally embedded this value.

Let us start with the *daily production process* that leads to having a lower weight Lack. Many of the resources involved in this daily process are the same as those presented in the previous section, even though some other resources become relevant in this process. These resources are presented on the *left side* of figure 4 below (the *right side* shows instead the resources involved in the daily utilization of Lack's low weight and will be discussed later).

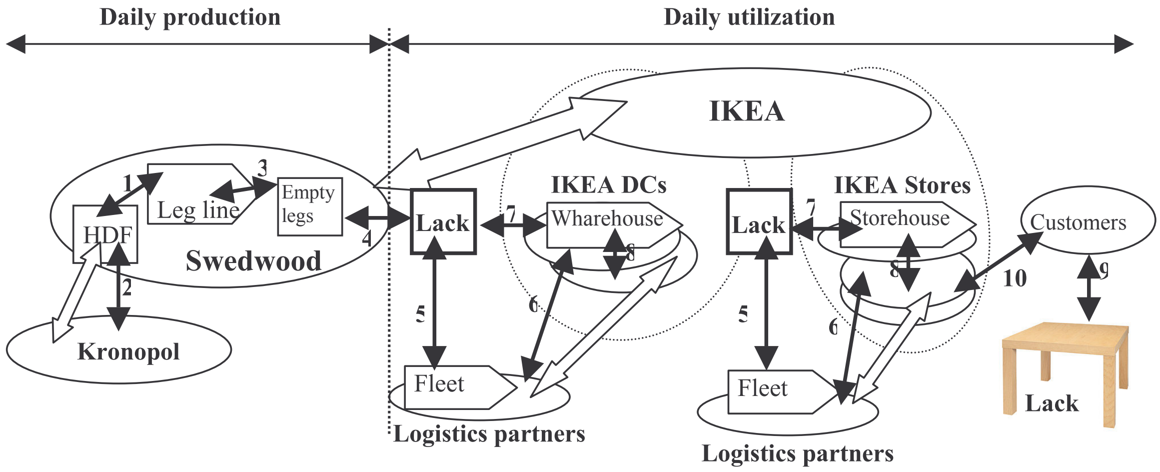

Figure 4: The resources involved in daily producing and utilizing Lack's low weight

The main difference compared to the value embedding process presented above is that we now look at how these resources are daily employed in a routine way. Therefore Wicoma, for instance, is not involved, unless machine breakdowns occur. In the daily value production some other resources become relevant: the interface *HDF-Leg line* (arrow 1 in figure 4) raises the issue of who delivers HDF. This introduces on the scene a new business unit, Kronopol, the sole supplier of HDF. Even though no special adaptations have been made by Kronopol to have its HDF fit into Swedwood's empty leg production, the manufacturing capacity of this supplier is extremely important to secure daily production: in fact, Kronopol is the only producer in Europe of the very thin 3 mm HDF that Swedwood needs in its production. Therefore an important interface is *Kronopol-HDF* (arrow 2 in figure 4): a specific coordination and reciprocal knowledge of production needs and capacity between Swedwood and Kronopol is necessary here, especially because Swedwood carries inventories of HDF enough only for two weeks of production. The business relationship between these two units is the channel that allows this coordination through daily orders and communications.

Within Swedwood then the daily production of empty legs takes place by handling the interfaces *HDF-Leg line* (from inventory management to production) and the last production interface *Leg line-Empty legs* (arrow 3 in figure 4). The knowledge necessary to do this is partly *built into* this key facility thanks to the development work reviewed above, and partly provided by Swedwood's manufacturing expertise and routines. These expertise and routines range from order management and production planning capacity to detailed technical knowledge on how to operate the leg line and control the quality of its operations. The last interface that produces low-weight is *Empty legs-Lack* (arrow 4 in figure 4): Swedwood needs here to organize its production knowing that the right leg will need to be packed together with the right table top. This requires keeping track of the exact volumes to be produced for the many variants of Lack: half a dozen different colors, square and triangular legs, and different lengths. Thus Swedwood needs the production planning ability to have the right legs ready at the *right time* to be packed with the right tabletops, without causing delays or piling up costly inventories that wait for their complements: for production planning Swedwood's ERP system Movex plays a key role, especially in interplay with IKEA's IT system for ordering, INOS.

At the same time, the *Empty legs-Lack* interface is also the first one that actually utilizes the newly produced lower weight feature: now a pair of scales would tell you that the packed Lack really weighs about a kilogram less than a solid-wood leg one. But this is just the beginning of a broader *process of utilization* of this value that stretches to the whole network on the right side of figure 4, where we encounter many new resources that were not involved in the original value embedding efforts. It makes sense to start by looking at the first business units that interact with Lack as soon as it starts its journey from Swedwood Poland to reach customers around the globe: these units are IKEA's logistics partners who pick whole pallets of Lack at Swedwood's delivery warehouse and load them on their railway wagons and containers. IKEA outsourced all of its logistics to hundreds transporting companies, but the overwhelming majority of IKEA's deliveries are handled by 50 close partners (e.g., Maersk, TNT and Scandi Interlink) with whom IKEA has long-term relationships. These partners have often huge transport fleet with hundreds of trucks and vessels (Maersk has about 200 ships!).

A key interface for the *direct* utilization of Lack's low-weight value in transportation is in fact *Lack-Fleet* (arrows 5 on figure 4): this interface concerns the single transportation mean – a truck or a wagon. Hundreds of pallets of Lack are loaded on these facilities from Swedwood warehouse in Poland to be transported first to IKEA's 30 distribution centers, spread on four continents, and then to IKEA's over 200 retail stores. The heavier the product and the more costly for Lack by each single kilometer: heavier loads consume in fact comparatively more fuel. Even if the weight loss thanks to empty legs for each single table is small, this should be multiplied by the 2.5 million pieces (and thousands of pallets) transported yearly over several kilometers around the globe. When logistic partners set a price for their services, they consider the weight of the goods they transport: it should not go over certain limits for total loads and, especially, for the most weight-sensitive facilities such as small trucks, goods weight is an integral part of cost calculations. In relation to every delivery, logistics partners invoice IKEA and the effect of having transported a lower-weight Lack becomes visible as a lower cost for IKEA in the interface *Logistic partner-IKEA units* (arrows 6 in figure 4).

From a knowledge point of view, having suppliers perform transportation activities not only allows IKEA to focus on its core activities (product development, warehousing and retailing), but is also an excellent way for IKEA to keep strict control and daily monitor transport costs, through logistics partners' invoices. But IKEA can also utilize internally the low weight value of Lack: both IKEA distribution centers and retail stores perform extensive goods handling activities, such as unloading incoming trucks or containers and filling storing areas and racks in their large warehouses. In addition, distribution centers also need to load pallets of Lack on outgoing transport facilities, while retail stores need to open these pallets and place single pieces in the exhibition and take-yourself areas. During these activities important interfaces emerge between the *lighter Lack* and all *internal logistic facilities* (see arrows 7 in figure 4): the forklifts, cranes and the floor personnel at IKEA's wholesale warehouses and retail stores can draw advantage from moving lighter pallets and pieces of Lack. This increases the speed of their operations, and reduces human fatigue or energy consumption by forklifts and cranes.

But another interesting effect of handling lighter Lack tables emerges in the interface between *internal logistic facilities* and the *IKEA unit* where they are located (arrows 8 in figure 4): this effect is a reduction of the internal logistic costs. But not everybody would easily notice this improvement: not because it is tiny (and indeed it is not, especially in relation to a low price item such as Lack), but because it requires a very specific and advanced type of knowledge to be identified, measured and tracked. In relation to this cost interface (but also to the one with transportation companies) IKEA has a special competence that is of pivotal importance: IKEA's whole business is based on a deep and almost scientifically developed knowledge of its costs across the whole supply, logistic and retailing network. Much of this knowledge is formalized within IKEA's *cost accounting system*, based on 53 cost items that are constantly monitored, also with the help of advanced IT systems (for a complete overview of these IT tools see Baraldi, 2003). Interfaces 6 and 8 are thoroughly scrutinized in this way.

Now, one could think that the value utilization process of Lack's low weight is over. Well, not yet. What about the interface *Lack-Customer* (arrow 9 in figure 4)? Individuals and families visiting IKEA on a Saturday afternoon are favored by a lighter Lack when they need to carry it to their cars: knowing this can increase their satisfaction with IKEA's total offerings and induce them to return to IKEA. However, the interface lighter Lack-Customer is also affected in a more concrete way: while strolling around IKEA's exhibition area, many visitors get the idea of buying things they had not planned. While this impulse easily lead to an actual purchase for such items as a potato peeler or even a frying pan, it is much more difficult to have it click for a table. Or at least, so it was until the further weight reduction allowed by empty legs: several IKEA customers purchase Lack tables by impulse and having it lighter eliminated an obstacle to this buying behavior. Therefore, Lack's low weight affects a final interface, *Customer-Retail unit* (arrow 10 in figure 4), by increasing the revenues of this unit and by increasing the effectiveness of their short-term price campaigns on Lack.

To summarize the whole value utilization process, low weight is a valuable feature for transport, distribution and retail units that can perform their activities at lower costs and hence for the IKEA that can make large savings. But low weight is also valuable for costumers that take Lack at home and for retail units that can sell more of it, especially those purchased by impulse. Therefore, some interfaces (e.g., *Logistic partner-IKEA*) utilize low-weight for cost reductions, whereas others (e.g., *Customer-Retail unit*) utilize it for revenue increases. The latter type of utilization was not planned by IKEA, who aimed to reduce transportation costs. Several forms of knowledge contribute to the daily utilization of Lack's low weight. These include general competence in performing internal and external logistic activities, but also a specific reflexive ability to analyze and calculate the cost and revenue structure associated with Lack: this was the ground to develop specific knowledge on what exactly affects Lack's costs in great detail and on how customers behave in relation to the product feature of lower weight. We focused on the individual interfaces where the low-weight feature is utilized, but there is a most fundamental and diffuse way in which the whole network (and especially the final customer) utilize low weight: this feature allowed further savings in transportation that in turn contributed to keeping Lack's retail price at €9.9.

5. The Holmen News case: the creation of a low-weight paper

The early 1970s were a turbulent period in many aspects, also for the paper industry. For a long time Sweden had been considered a forest country. However, in the beginning of the 1970s the industry expected an imminent wood shortage, which would lead to increased prices. Since the paper industry was a huge user of wood, increased wood prices were seen as a great threat. Another important issue at this time was the OPEC negotiations in 1973 that led to a dramatic increase of oil price and what was to be known as the "oil crisis". Since the paper industry was a significant user of oil, the increased cost affected profitability severely. Both these events induced the paper industry and the focal business unit in this case, *Hallsta paper mill*, to start searching for methods and technologies that could save on these two raw materials, *wood* and *oil*. Hallsta was founded in 1915 to serve the growing newspaper market in the Stockholm area. Today about 1000 people work at the mill, owned by the large paper company Holmen, and Hallsta's customers are mainly the large publishing companies in Germany, France, Holland and Great Britain.

In the early 1970s Hallsta consumed huge quantities of wood and faced the threat of higher wood prices: finding a technology that could be more wood-efficient became a priority. In addition, Hallsta consumed large quantities of oil in two major activities, the production of chemical pulp and of steam that was used in the drying section of paper machines. A solution to the increased cost of both raw materials would be to produce a paper with lower grammage weight based only on mechanical pulp. This solution excluded all insert of chemical pulp previously required to strengthen the pulp. But a new type of mechanical pulp was needed, that was not present at that time. However, with such a paper, fewer fibers would be needed to produce the same printing surface. And fewer fibers would also be steamed in the drying of the paper, and accordingly less oil would be needed. This change was to be far from easy to manage. Several interfaces, both technical and organizational had to be molded and coordinated before this could happen on a broad scale and the control of the change was never solely in the hands of Holmen and Hallsta. Today, Holmen market a product, *Holmen News*, with a reduced grammage weight that range from 42 to 45 grams per square meter.

5.1 Creating low weight paper at PM12

In the early 1970s the standard grammage weight for newsprint was 52 grams per square meter. This standard was accepted both by the users and customers, the printing houses and publishing companies and by the producers, the paper mills. When Hallsta decided to move from 52 down to 48 grams, the goal could be attained only if several technologies improved. The involved engineers understood that *"a lower grammage weight per square meter puts some serious demands on the final product, the newsprint. And as paper is produced by pulp, new requirements on the pulp were made, and thus accordingly also on the technology that produced the pulp".* A technology to produce a stronger pulp was accordingly needed.

Until 1974, Holmen based its paper production on the Stone Ground Wood (SGW) pulping method, where wood logs are pressed against a rotating stone. As this method shortens the wood fibers, chemical pulp had to be added to the pulp in order to create a pulp with the right features, especially strength. The SGW method had been the dominating pulping technology for almost 100 years, when the expected shortages and increased prices in wood and oil made some firms question the established technology. In 1974, Hallsta was about to invest in a new paper machine and more pulping capacity was needed to supply it. The board of directors of Holmen had decided to invest in the SGW technology, but then came the oil crisis and the reports on wood shortage. Suddenly, they decided to abandon the old established technology in favor of a new, unproven one, Thermo Mechanical Pulping (TMP). *"The accounting people had given us some reports and we could see how margins would be affected by the increased prices. We had to do something"*, as one of the involved people puts it.

Another unit within Holmen had already been supplied by Defibrator with equipment for board production, where pulp was produced in so called *disc refiners*, by beating wood chips between two counter-rotating discs or plates. The quality of the pulp had however not been high enough to be used for newspaper production. Still Hallsta decided to invest in disc refiners from Defibrator in 1974. An engineer at Hallsta explains the choice of supplier: *"Defibrator had long experience from developing equipment for the paper industry and was known to be a very innovative company. They had worked with wood chips defibration and they were already a supplier to another Holmen facility."* Defibrator had started to develop the refiner technology in the late 1960s and wanted to move it into pulp production for the newsprint industry. In Hallsta they found a customer that had clear incentives to introduce the technology and that could become a reference mill for other customers: Defibrator needed a reference customer for the new technology and Hallsta needed a process that could help it to lower its oil consumption, its chemical pulp use and produce a paper with lower weight.

The relationship became very close and the two parties jointly developed the TMP process. Hallsta was the first wholly integrated paper mill to invest in the technology and therefore quality issues were of great importance. Early quality problems included the high content of shives, unprocessed fibers that caused problems in the paper machines, and more critically in the customers' printing processes.

By increasing the intensity in the refining and changing the patterns of the segments, these problems could be overcome. These changes were based on trials and errors: *"Still today, we don't know what happens inside a disc refiner, even if the knowledge certainly has increased on what parameters to use in order to increase pulp quality"* as an engineer at Defibrator (now Metso) puts it. Mechanical problems in the production process were another area where the joint development work was intimate.

Eventually, a number of benefits could be reached when the pulp attained an acceptable quality level, measured on the quality index Freeness, which indicates the pulp's drainage ability in the paper machine. This index indicates also other features such as certain strength properties. However the relation between features is not explicit but again based on operators' experience: they know that by increasing the refining intensity, paper gets stronger as the length of the fibers increases. Thus, less chemical pulp was then needed as reinforcer. As chemical pulp only consists of 50% wood, paper based solely on chemical pulp risks having too low opacity. Hallsta realized that a higher share of mechanical pulp increased the opacity, which allowed producing a thinner paper, a paper with *lower grammage weight*! As the TMP technology reached higher grounds, Hallsta and Defibrator started to invite other customers and taught them how to run TMP mills, how to avoid quality problems, what pulp recipe worked for what products, etc. As one engineer at Defibrator put it: *"The development of the TMP process lay the ground to lower the use of chemical pulp and facilitated the development towards a thinner paper. The relationship with Hallsta was instrumental in this process."*

A few years later another innovation further reduced the consumption of oil in paper making. Defribator managed to pressurize disc refiners so that the large amounts of steam created there could be recovered and used in paper machines' drying section. The need for steam here had already been reduced by a stronger pulp, moreover now it was provided by the pulping step: thus Hallsta's oil consumption almost disappeared from one year to another. However, joint development efforts with Defibrator were not enough for Hallsta to develop a lighter paper: a complementary development was necessary in *electronic control devices*.

A critical factor for Hallsta to meet the target of 48 grams per square meter was the possibility to control the paper web's profile on a continuous basis, on-line. When the grammage became lower, the paper got thinner, which meant that the numbers of running meters per roll of paper increased. This required a much more even paper profile, because small irregularities along the paper web caused problems on the rolling machine and on the tambour, where the paper is cut to dimension. To tackle these problems Hallsta collaborated with ABB, who had supplied Holmen production sites for some time with control devices. Hallsta had already invested in ABB's AccuRay system, which was further developed to handle thinner paper. One of the paper machine managers describes in this term the relationship with ABB: *"The cooperation was quite intimate with ABB. We had long discussions on what was possible to do and they explained for us how we could reach our goals. Then there was an education package for the operators in order to get to know how the new systems worked, how to interpret the different measures etc."* The knowledge that ABB had developed around AccuRay, in other relationships with paper producers, could be applied within the new setting at Hallsta.

The supplier of paper machines Voith also contributed to solving Hallsta's problems with low grammage by developing the paper machine in a key dimension. The "free draughts" in paper machines had historically played operators bad tricks, since they are the areas where different sections interface to each other (e.g. the pressing and drying sections) and where the paper webs hangs loose. This required a very strong paper web and constrained the speed of paper machines. The paper web was stretched in the free draughts and if it contained shives or weak parts, the whole web broke down and the paper machine had to stop. Every stop is extremely costly, and a high priority goal is to lower unplanned stoppage time. Thus Voith made the free draughts of the new paper machine, PM12, less "free": this development could have eased up strength requirements, but it also allowed increasing speed in the paper machine to make the process more efficient. Therefore, despite the elimination of free draughts, the paper web had to become stronger due to the increased speed. Such strength depends on the fiber-to-fiber bonding created in the pulping process, when wood fibers are defibrated. By examining how the features of the pulp changed with increased load and changed segment patterns, Hallsta improved the strength quality of its pulp: Hallsta and Defibrator found out together that the higher the intensity in wood refining, the stronger pulp. As a consequence, the higher load necessary to increase refining intensity led to an increased use of electricity.

The operators gradually learnt how much pulp had to go into the paper machine and how the paper machine was to be controlled. In practice, it meant decreasing the amount of pulp from the silo into the paper machine. Simultaneously the demands on opacity were increasing. One of the customers had had problems with advertisements where it was possible to read the ad from the opposite page. As the manager for PM 12 put it: *"In order to solve this problem, the operators had to put in clay that increased opacity. This is a kind of common knowledge in the business, all the paper mills do the same when they face this type of problem. But how much and in relation to what paper grades is highly specific"*. At this time, waste paper emerged as a new raw material. Since waste paper consists of magazines and journals, which in turn contain large shares of chemical pulp, mixing it with fresh fiber was a way to increase strength features while reducing the amount of pulp wood. Waste paper was also in the 1970s a very cheap raw material, which no one really wanted. However, the paper industry saw waste paper as a second rate raw material, nothing to shout out about. *"We saw the economic benefits by investing in a waste paper mill, but still there was this image issue that not was positive. In the end economics was more important."* For these reasons, Hallsta invested in a waste paper pulping facility in 1975 to balance the dependence on wood as a raw material.

Lower grammage was something that also Hallta's customers wanted: one of these is Dagens Nyheter, Sweden's biggest newspaper. But to avoid unwanted effects with a lower weight paper, Holmen and Dagens Nyheter had to work together until the printing presses could run smoothly. In printing processes, a thinner paper, if it also is weaker, can create great problems, such as web breaks. Thus, Hallsta and Dagens Nyheter's printing house in Marieberg together trimmed the printing process based on a thinner paper. A lower weight paper can cause problems not only for Hallsta's customers, but also for the customers' customers: when the paper gets thinner, opacity can become insufficient, that is, the paper become transparent and ads or pictures can be seen from the other side of a page. Thus, the amount of ink and how pictures were composed had to be adapted to the new grammage. This was something that Dagens Nyheter in turn had to teach its customers and the advertising agencies. The ink producer Akzo also had to adapt its products to the thinner newsprint.

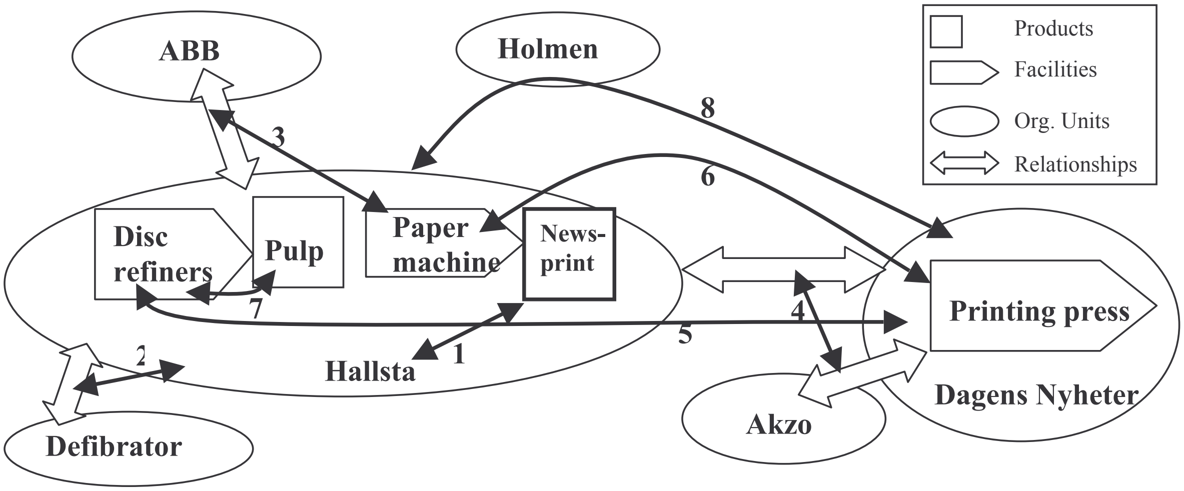

Figure 5: Some of the resources involved in creating low-weight Holmen News

The resources that embedded low-weight value in Holmen's News are illustrated in the figure above. We have selected eight specific interfaces that are more explicitly scrutinized:

1) *Hallsta-Newsprint*: for the unit that produces the paper there were clear benefits in going from 52 to 49 and then to 45 grams per square meter. Dependence on wood and on oil would decrease and this would increase (or maintain) profitability for Hallsta and Holmen. The knowledge to realize this was in-house due to the production personnel's long experience.

2) *Defibrator-Hallsta*: this relationship was pivotal for introducing the pulping technology that decreased wood and oil consumption. Knowledge that developed within the relationship was critical for both companies at a time when the technology was relatively unproven.

3) *Relationship ABB/Hallsta-Paper machine12*: the relationship between Hallsta and ABB is directed towards the production facility PM12. The knowledge about industrial control systems had been developed at ABB for many years in several business relationships and the experience of producing paper has a history of several decades in Hallsta. The ability and the motivation to solve production problems and develop the machine' capabilities to control the paper web's profile on-line was high at both parties.

4) *Relationships Dagens Nyheter/Akzo-Hallsta/Dagens Nyheter*: this interface involving three firms is "sleeping" because they interact only when there is a specific need for it. With a lower grammage there was a need to coordinate the use of inks and damp in the printing process. Thus, there was a need to engage Akzo, the supplier of ink and chemicals, in order to fix problems of opacity, set-offs, web-breaks etc. Dagens Nyheter's personnel works specifically with the products from specific paper machines and know from long experience how it reacts with different types of inks and chemicals.

5) *Disc refiner-Dagens Nyheter*: this is an "invisible interface" as the development in the TMP technology towards a stronger pulp impacts the possibility for newspapers such as Dagens Nyheter to go down in grammage weight and print more efficiently. Few people are aware of this interface, namely Hallsta's Technical Marketing function, which can tell customers how strength features created in the TMP process affect the printing press.

6) *Paper machine-Printing press*: this interface links two production facilities that interact systematically with each other, regardless of the actors involved. The printing presses at Dagens Nyheter are supplied with paper from specific paper machines, since the paper features are created in a paper machine are almost unique, even if newsprint is considered to be a standard product. This induced the printing site of Dagens Nyheter, to combine its three printing presses with paper from certain paper machines and with inks from specific suppliers in order create satisfying resource combinations in the printing presses.

7) *Disc refiner-Pulp*: this interface creates many of the features later activated in the paper machines and in the printing presses. For example the strength so critical to producing a thinner paper are created in the TMP process. The knowledge to create these features has traditionally been very experience-based, but is getting more and more formalized.

8) *Holmen-Dagens Nyheter*: the interface between Holmen and Dagens Nyheter also involves Holmen's production units, such as Hallsta. Dagens Nyheter's demands on a lower grammage weight were channeled into the production units and back to the printing sites. There had to be some interaction between the producer and the user of newsprint in order to create both a reliable printing process and a nice looking end product, a newspaper with lower grammage.

5.2 The daily production and utilization of low-weight

Low weight grammage is daily utilized in several ways and by several actors in the network around Hallsta. There are several actors with economic incentives to use a lower grammage and the ambition here is to illustrate how these incentives are put into action by the coordination of interfaces between technical and organizational resources. Wood is the main input in a chain of activities: it is first cut into small chips and then defibrated in the disc refiners that produce pulp. Today, Hallsta has TMP units that produce almost all of its pulp. Pulp is then the input for paper making, which basically consists in taking away most of the water from the pulp to create a web of wood fibers that bind to each other into a paper sheet. In order to accomplish this, a paper machine consists of three major parts or sub-systems. The first step is the vire section, where the draining activities start and the paper web get its basic "profile". In the second step the paper web goes through a pressing sectiont, where further water is drained from the web. The last step contains a drying section where further water is heat-dried from the paper web. The thicker the paper, the longer it will take to dry it and thus, the more heat is needed. Producing heat is energy demanding and was for long done with oil.

One key interface in the daily utilization of lower grammage is the one between Hallsta's *PM12* and *Dagens Nyheters new printing site,* DNEX's, *printing presses* (arrow 1 in figure 6). The paper quality is tried out with the customer, and its features should be held constant so that the printing process is reliable for the customer. Dagens Nyheter's printing site monitors paper quality several times a day to identify discrepancies and the exact paper roll that caused problems. Thanks to bar-coding, Hallsta can consult its IT system to see if there were any profile problems on that paper web in their production.

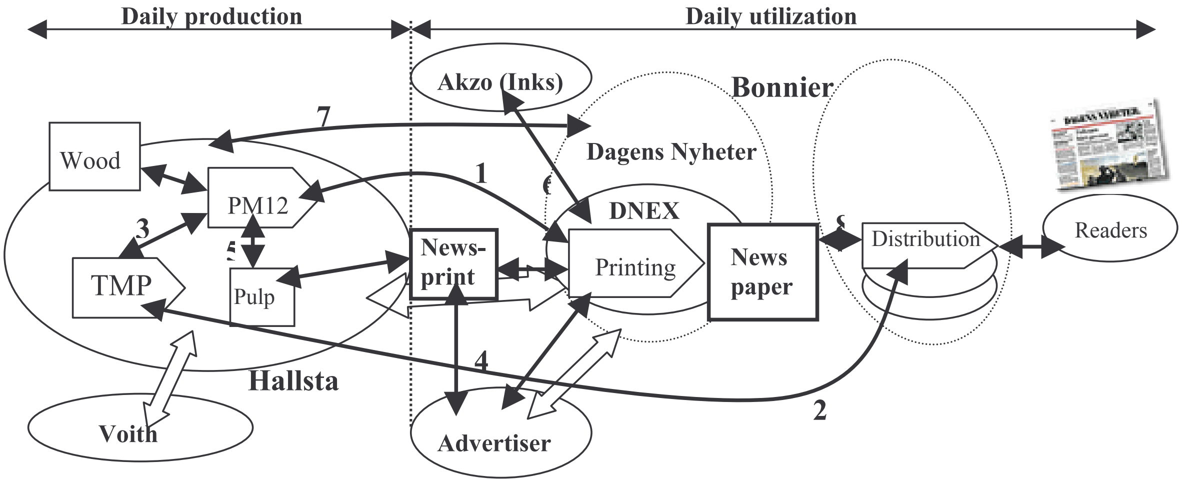

Figure 6: The resources involved in daily producing and utilizing newsprint's low weight

Low weight is utilized since the very beginning of the printing process, when paper rolls are manually charged, thus the interface between *paper* and *printing press* is important. How long a paper roll lasts depends on the paper grammage: the thinner the paper, the longer the paper roll will last, and this is positive for several involved actors. Individual operators' work gets smoother, since they need to change fewer rolls. Purchasers save money since the paper is priced per ton: more printing surface in a longer roll is paid the same amount of money. Finally, newspaper distribution gets more efficient when the paper has a lower weight: a publisher is able to print the same numbers of newspapers, with a 9% lower weight. The transport means to distribute the same number of newspapers can be reduced. And the last component in the chain, the delivery man, can now carry lighter newspapers.

Another interesting interface links *TMP* and *distribution* (arrow 2 in figure 6). A thinner paper makes the whole production system a little bit more vulnerable and dependent on the strength created in the TMP process. In fact, if the paper is breaks in DNEX's presses, distribution can be delayed and the publisher cannot charge money from advertisers for newspapers reaching the reader too late. Thus, distribution is dependent upon the features created long back in the resource network. The producing unit Hallsta too utilizes lower grammage: a critical interface in daily production is the one between *PM12* and *TMP* (arrow 3 in figure 6). These two facilities must coordinate both volume requirements and quality demands. PM12 has clear demands on the strength features that the pulp must meet in order to function properly in its operations. The feature that TMP continuously measures is *freeness*, a very crude measure of the pulp's drainage properties on the paper machine. A high freeness indicates that the fibers are not well bonded and that drainage will be smooth. But a high freeness also indicates other things, such as that strength features are low. Thus, the knowledge of the level of freeness that TMP should produce is very experiential and is always in relation to a *specific* paper machine.

Arrow 4 in figure 6 illustrates the interface between the *advertising firm* and the *product newsprint*. This interface is crucial for the whole network. The more knowledge advertisers have about the newsprint features, the better will the final print become. DNEX, the printing site, contributes to spread this knowledge in the network. The interface between the *pulp* and *PM12* (arrow 5 in figure 6) determines the economy for the paper machine. A stronger pulp makes more efficient paper making and reduces disruptions. But a stronger pulp requires consuming certain resources. This interface spread thus to TMP the demands from the paper machines, which are so economically important for the paper mill.

DNEX and the *ink manufacturer Akzo* have developed a rather close interface (arrow 6 in figure 6): the more adapted the whole process is in relation to a certain newsprint grade, the more will also printing ink have to become adapted to create good runability and printability. The interface *Hallsta-Dagens Nyheter* (arrow 7 in figure 6) rests on a long term relationships started in the 1900s when Holmen started to supply newsprint to Dagens Nyheter. It was also in the relationship with Dagens Nyheter that Hallsta established the new standard, low weight paper, and was able to spread it to other customers. The relationship with Dagens Nyheter is often the start of new product refinements that later on become a standard grade for smaller customers. Finally, the interface between *newspaper* and *distribution activities* (arrow 8 in figure 6) is critical. Even if the low grammage feature is institutionalized, it can not really be taken for granted. Now and then printing presses have web breaks that delay distribution and sometimes the newspaper is not distributed. This interface is a critical one for the economy of a newspaper company as advertisers will not pay for ads that never reached consumers.

6. Analysis and discussion: knowledge forms and value

Based on the two empirical illustrations, we now analyse the *knowledge forms* involved in the original value embedding and in the daily value production/utilization processes for the low weight of Lack and newsprint. We also discuss the barriers to developing and applying this knowledge that derive from the network. We start from a single resource interface for each case and we show the knowledge forms that intervene in that interface, according to the four forms in the matrix of figure 2. Then, we expand our analysis to the whole network and similarly break-down the knowledge behind the whole value creation process. Finally we compare the two case studies from a knowledge perspective and in relation to the embedding network. We point out here the possibilities and the limits to knowledge development and value creation that the existing network and the knowledge that it already hosts can create.

6.1 The knowledge forms behind Lack's low weight

One of the key interfaces involved in the value creation of Lack's low weight is between Swedwood's *leg line* and *empty legs* (see arrow 8 in figure 3 and arrow 3 in figure 4). There are several knowledge forms (types and levels) related to this interface that contributed to the original embedding of low-weight and to producing and exploiting this value on a daily bases. First of all, the machine itself is a form of knowledge: the leg line, being a very specialized machine, embodies a lot of *interface-specific* knowledge just on how to handle several other interfaces, that is, on how to bend 3mm-thin HDF sheets around chipboard cubes into Lack's empty legs. This machine embodies knowledge on the *outcomes* to be produced by combining these components, without any causal relations knowledge needed to have it work…indeed the main goal with developing this machine was to automate this manufacturing operation, without the need to ask or know why the machine works so at any step. Thus, the embodied knowledge of the leg line belongs to the right upper quadrant in figure 2.

But if we take a step backward, before the machine was engineered, other forms of knowledge appeared in the value-embedding process: knowing that IKEA would buy Lack tables from Swedwood for a long term motivated economically investing in developing a new purpose-specific machine. This is *interface-specific outcomes* knowledge, that is, specifically on the relationship IKEA-Swedwood and concerning the outcome of satisfying this key partner. But Swedwood also used *conceptual* knowledge in the form of calculations on investments and on the reasons why IKEA sticks to a supplier (joint investments, IKEA's dependency and Swedwood's historical positive track). Then, the conceptual and interface-specific knowledge inside Swedwood accounting system suggested that changing component materials for empty legs would increase production costs too much. This led to keeping 3mm HDF and chipboards, the knowledge constraint for the outcomes knowledge behind the leg line: "do whatever you want as long as you use these two resources and obtain light, empty legs".

As for the technical details in the interface "leg line-empty legs", there are two major sources for the underlying knowledge: Swedwood's long-term experience and skills in working with 3mm HDF and chipboards – an *interface-specific outcomes* knowledge (such as knowing that HDF sheets must be carved at a certain angle) – and Wicoma's more *general* and *conceptual* knowledge of models over engine powers, calculations on carving angles, and formulas to select the right cutting tool. At the same time, Wicoma also had an extensive experience-based knowledge of Swedwood's processes: in this way Wicoma made available a great deal of *outcomes* knowledge that was *both* generalized (on any wood-working machine) and interface-specific (on machines capable to cut and combine HDF and chipboard).

In the daily value production and utilization process, the manufacturing knowledge embodied in the leg line is automatically applied as "black-boxed" outcomes knowledge. At this stage some other bits of knowledge affecting the “leg line-empty leg” interface enter the scene: Swedwood’s production skills, both generalized and interface-specific ones, that is, those on how to combine 3mm HDF and chipboard; Swedwood’s quality control routines to evaluate the inputs-outputs of the leg line; Swedwood’s production planning routines, a generalized outcomes knowledge aiming to assign the right production lots to the right machine and a more specific operational knowledge on how to plan the production of Lack legs, given their different shapes and size (part of this knowledge is embodied into Swedwood’s IT system, in the form of the conceptual models for inventory and production planning); Swedwood’s order management routines and their link to IKEA’s ordering routines, an interface-specific outcomes knowledge that is a precondition for starting utilizing Lack’s low-weight, namely for having IKEA’s purchase orders properly translated into production orders at Swedwood.

But the interface “leg line-empty legs” is just one among many others involved in the process of embedding, production and utilization of Lack’s low-weight value (see figure 5 and 6). With so many interfaces involved there ought to be many more knowledge bits dispersed in the whole network, from producers to logistic and retail units. The matrix of figure 8 presents a broad overview of the key knowledge bits behind value creation, according to their forms.

	Generalized interface Knowledge	**Specific** interface Knowledge
Outcomes knowledge (know-what and know-how, *operational*)	Machines not specialized in handling Lack: trucks, warehouses and storehouses Swedwood’s expertise on wood, Wicoma’s on machinery, IKEA’s on logistics or consumers Swedwood’s production plan/ordering routines, IKEA’s goods handling/merchandising routines	Leg line: a single-purpose machines only for Lack Swedwood’s expertise on HDF-chipboard (e.g., carving angles), Wicoma’s on Swedwood’s machines, IKEA’s on plastic legs-consumer tastes Swedwood’s routine to order Kronopol’s HDF, Swedwood planning for Lack, IKEA ordering Lack Lack’s blueprint and bill of materials
Causal relations knowledge (know-why, *conceptual*, understanding)	IKEA’s calculations on internal/external logistic costs, Swedwood’s on investments Mech. engineering theories (Wicoma), furnit. construction (Swedwood), logistics (IKEA) IKEA’s IT system for ordering (INOS), Swedwood’s ERP (Movex) IKEA’s accounting system (53 lines), logistic partners’ invoicing system	Spec. calculations on Lack’s costs, on leg line invest., on sales/preferences for low-weight Lack Models applied on leg line functioning or Lack’s logistics flowchart Electronic demand forecast/planned orders of Lack, Lack’s electronic/interactive bill of materials Line X (of 53) about Lack’s transport costs, specific invoice from carrier Y

Figure 7: Types and levels of interface knowledge behind Lack’s low weight

Figure 7 shows the great variety in the knowledge necessary to create and exploit the low-weight value of Lack: from knowledge concerning wood-handling technology to knowledge on transportation and internal logistics, and especially on how to calculate the costs of these activities, to knowledge on consumer’s tastes and shopping behavior (such as impulse purchases). The using side of the network does not need to know much about Lack’s low-weight to draw advantage from it. Consumers need for instance just to “feel” that Lack is lighter and can easily be picked up. Carriers, IKEA distribution centers and retail stores constantly monitor their operation costs and can realize that the lighter pallets of Lack can be handled faster and by saving other logistics resources (people, forklifts, etc.). Similarly, retail stores can make calculations on the *specific* effects of a lighter Lack on increased sales.

The same low-weight feature is utilized to satisfy different needs, those of different actors that use low weight in different activities and interfaces. At this level, the knowledge involved must become more *interface specific* to allow an actor *fully utilizing* Lack’s low weight by *adapting* other interfaces to it (e.g., with internal logistic resources) to provide further savings or advantages. In fact, when knowledge is applied to specific interfaces, possibilities appear to develop each of them, such as reducing the number of people that move pallets of Lack or placing more pieces of Lack on the same rack, or shortening internal logistic times attributed to Lack, with benefits for sales. But not everything can be developed at a certain moment, because the network also entails hindrances as to what can be changed and the directions of such change, as we shall see when discussing knowledge politics concerning Lack.

6.2 The knowledge forms behind Holmen Newsprint's low weight

An important interface in the value creation and utilization processes of Holmen News is the one between the *TMP pulp* and *PM12* (see arrow 5 in figure 6). This paper machine, like the leg line above, is a form of embodied knowledge, where experience and conceptual knowledge has been moulded into the facility during decades. But differently from the leg line above, PM12 was not engineered specifically to handle just low grammage paper: it is therefore a form of *generalized* interface knowledge. What is instead specific is the knowledge necessary to trim the various sections of this machine so that they can interplay at best with the new pulp features. PM12 was thus adapted to TMP pulp through very *interface specific* knowledge developed on site at Hallsta, but in cooperation with suppliers such as ABB and Voith. PM12 and the pulp were indeed mutually adapted: the right level of pulp strength, so important as the paper gets thinner, was found by involving external suppliers. The paper machine supplier in particular applied its knowledge developed in relation to other customers and accumulated during almost 100 years. This knowledge started as *conceptual and general*[3] but became interface-specific at Hallsta in order to be useful for this user. When a machine is installed, suppliers instruct Hallsta's operators, to explain how the machine works and reacts to specific stimuli (raw material, speed, etc.). However, soon the users know more about the machine than the suppliers, and knowledge is translated in the opposite direction.

Another knowledge that led to embedding the low weight feature in Holmen News was the knowledge provided by ABB and embodied in its AccuRay control system. This knowledge was *conceptual* and *general* at first, but was then tailored to Hallsta's specific conditions, thus turning into *specific interface* knowledge. Moreover ABB's knowledge soon focussed on outcomes and was black-boxed: when a paper machine runs at 1500 meters per minute and the production goal is 200,000 tons of paper a year, there is no time to wonder about why a machine behaves in a certain way or what mechanical laws intervene when pulp moves from the pressing to the drying section. ABB simply provided knowledge black-boxed inside its electronic control system. Operators can follow inside AccuRay the paper web's profile (its grammage), and they can adjust it from the control room if the need so. But if something serious happens, such as a web break, the operator has to go in the machine hall and fix it manually in a short time. For this, operators need a deep *operational* knowledge about how the machine works, where problems tend to occur and how to avoid them. Differently from AccuRay's *generalized* knowledge, the operator's is very *specific* for PM12. It takes about a year of learning by working at PM12 before an operator is regarded as a "full" crew member.

Pulp, the input to the paper machine, is produced based on a *mix* of generalized and interface-specific knowledge. Defibrator supplied a technology largely based on long traditions and practical experience, hence *outcomes* knowledge. Pulping requires in fact knowing that a specific disc refiner run with a certain wood quality and a certain segment gives a pulp with certain specific features, but without explaining *why* this happens. Based on a generalized knowledge of such outcomes, the actors need to engage in *on-site* trials and errors, trying various combinations of the above resources until the adequate pulp features are obtained with acceptable costs and in the *specific conditions* at Hallsta. Since Hallsta is on the technical forefront and often tests new techniques, Voith, Defibrator and ABB can in turn generalize from the specific interface knowledge developed at Hallsta and translate it to other customers.

The stimulus to reduce the paper's grammage was information inside Hallsta's accounting system: oil had become more expensive and Hallsta needed to save on it. This is knowledge at *conceptual* level and is *interface-specific* because it concerns the cost of a specific resource combination. This cost information relies on specific knowledge of how much Hallsta would save by producing newsprint with lower weight. However, the costing system was built upon *general* knowledge of the cost structure relating Hallsta's functions. Thus, in order to reflect the new technical and economic interfaces that TMP would entail, more specific and adjusted accounting knowledge had to be created: PM12 would "buy" steam produced by the disc refiner unit instead of oil from external sources. Further, internal costing knowledge had to be matched with general knowledge on Hallsta's customers cost structures, in order to identify their incentives to use a lower weight paper. But still, this attempt to conceptualize the new pulping technology in the form of accounting knowledge may clash with the *operational* knowledge on which the technology is largely based. Thus, decisions grounded only on this

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[3] In relation to this case the knowledge must be seen as such. Historically, however, paper making was seen as a craft and the development more based on a type of knowledge that is closer to outcome-like.

accounting knowledge can change resource combinations into directions that increase instead of reducing costs. Operational and conceptual knowledge is indeed "layered" in this case.

	Generalized interface Knowledge	**Specific** interface Knowledge
Outcomes knowledge (know-what and know-how, *operational*)	PM12 and the generally designed interfaces with pulp in its different sections ABB's AccRay electronic control system to steer the paper machine and the input pulp Generalized experiential and trial-and-error efforts by Defibrator to develop disc refiners Defibrators knowledge on how wood fibers react to defibration	Tests on PM12 to use Hallsta's TMP pulp in the paper machine. Voith and Hallsta's experience TMP operators' ability to choose segments in relation to wood type. PM12 operators' experience Defibrator experience and Hallsta's use of refiners DNEX's know-how to combine printing presses with specific inks and papers
Causal relations knowledge (know-why, *conceptual*, understanding)	Principles behind ABB's electronic controls Holmen's general knowledge of internal and customers' cost structures as a basis to use TMP and low grammage paper Defibrator's "theories" for developing refiners	Specific fiber-to-fiber bonding determines strength and possibility to exclude chemical pulp and run the machine faster Cost calculations on PM12 using oil and on the economic benefits of using steam from the TMP instead of buying oil

Figure 8: Types and levels of interface knowledge behind Holmen New's low weight

As is illustrated in figure 8, several forms of knowledge intervene in creating Holmen New's low weight. This knowledge is highly dispersed and the using side of the network needs not know as much as the producing side about the feature of low-weight to draw advantage from it. Printing houses need to adjust their printing presses and the amounts and type of inks to a paper that is thinner to avoid jeopardizing the opacity of the paper or the runability of the press. Still, in utilizing the low weight in newsprint different forms of knowledge must intervene. The specific interfaces between printing presses, inks and paper must be tested at Dagens Nyheter's printing site, DNEX, where press operators adjust then the control mechanisms on site. The low weight of newsprint is utilized by different actors working in different conditions. And there is a need for different forms of knowledge to take advantage of this feature. This knowledge has also to consider other interdependent features, such as strength, that can cause conflicts for users.

6.3 Comparing the two cases: knowledge, interfaces and value

We now compare how knowledge develops and is applied in the two cases. The comparison of figure 9 relies on the following indicators that relate knowledge with network issues:

1- *technical interfaces:* technology complexity and number of indirect/hidden interfaces;

2- *knowledge dispersion:* variety of competences required and spatial diffusion at several loci;

3- *organizational interfaces & knowledge coordination:* number and variety of actors involved, the distribution of their initiative and efforts, type of dominating rationality;

4- *knowledge politics:* conflicts concerning knowledge development and application;

5- *barriers/openness* to the development of (new) knowledge, resources and value;

6- *roles of the four knowledge forms:* specific/generalized and operational/conceptual.

Six indicators	Lack	Newsprint
Technical interfaces	-Simple interfaces, limited numbers of technologies (one key facility). -Visible/direct interfaces between production and use of the feature low-weight.	-Complex interfaces, many different technologies (several key facilities). -Many hidden/indirect interfaces between production and use of the focal feature.
Knowledge dispersion	-Restricted competence span required. -Fewer actors involved in value embedding. -Many actors utilize the value, with limited need of knowledge on it.	-Broader competence span required. -Many actors involved in value embedding. -Fewer actors utilize the value, but intermediate users need much knowledge on it.
Organizational interfaces & knowledge coordination	-Inter-org. interfaces actively handled by IKEA with goal to develop knowledge. -Tight coordination of knowledge dev. -One actor with knowledge and motivation takes initiative and overviews the process. -“Overall” rationality.	-Many inter-org. interfaces but not handled explicitly for developing knowledge. -Loose coordination of knowledge dev. -Several actors know but no one takes strong initiative: steering at each other? -“Local” rationality
Knowledge politics	-IKEA’s interests against the network, but also for the network if gains for all exist. -Minimal need for compromises. -“Steered” knowledge dev goes faster.	-Several conflicting interests need to converge, but no mediator exists. -Many local compromises. -Implicitly growing knowledge takes time.
Knowledge barriers	-Knowledge on specific resources blocks other technologies: HDF Vs alternatives -IKEA’s goals and investments block other value options: a thinner Lack? No thanks!	- Development efforts on specific features make it hard to focus on others later on. -Focus on wood yields from pulping Vs energy issues (for the producer and user)
Role of the four forms of knowledge	-Conceptual kn. initiates resource development: notice problem by calculation. -Operational kn. dominates daily value production/utilization. -Specific kn. is needed to develop a particular interface -Generalized kn. initiates dev., broadens solution search, diffuse use in new interfaces	-Initiated by cost analysis that higher oil price would lead to decreased profitability -Operational kn. dominates daily production -Specific knowledge is needed in order to change and develop a certain interface -Generalized knowledge is moved and translated into specific knowledge during periods of change.

Figure 9: Comparing knowledge development and application in the Lack and newsprint cases

1) Technical interfaces: The creation of Lack’s low-weight value relies on knowledge applied to fewer and relatively less complex technical interfaces than in the newsprint case. Moreover, Lack’s value relies basically on two main technologies – wooden furniture manufacturing and logistics – whereas newsprint’s low-weight is created and utilized through several technologies – foresting, pulp making, paper production, printing, advertising and logistics. Accordingly, there is only one facility that is essential for Lack’s low-weight, that is, Swedwood’s leg line, compared to the many facilities that play a key role for newsprint (disc refiners, paper machines, printing presses and distribution). The newsprint case presents also several indirect and hidden interfaces between production and use of the focal low-weight feature (see interfaces 1 and 2 in figure 6), compared to the quite visible and direct interfaces between production and use of Lack’s low weight (see figure 4).

2) Knowledge dispersion: The range and variety of competences required to create Lack’s low-weight is much more restricted than those behind newsprint. Whereas for Lack it is enough with knowledge in logistics costs and operations, wooden materials, furniture production, and basic mechanical engineering; newsprint requires knowledge in mechanical defibration of wood fibres into pulp, in paper and ink production, in printing, in advanced mechanical engineering, robotics and automatic production control for both paper making and printing. Not surprisingly, only 3 actors/business units are involved in the embedding of low-weight in Lack (figure 4), whereas as many as 6 intervene for newsprint (figure 6). Another important difference concerns knowledge on the using side: whereas several actors utilize Lack’s low-weight value and they do it with very limited knowledge about it, newsprint’s low-weight may be utilized by fewer actors, but intermediate users such as printers, need to have extensive knowledge on this new feature to be able to exploit it.

3) Knowledge coordination: The Lack case presents inter-organizational interfaces that are actively handled by IKEA with the goals to develop knowledge to sustain low-weight. By converse, around newsprint there may be even more inter-organizational interfaces in the form of ongoing business relationships, but these are not handled with the explicit purpose of developing knowledge on low-weight. Therefore, whereas around Lack knowledge coordination is *tight*, it is much *looser* around newsprint. This reflects the fact that one single actor, IKEA, has both knowledge enough and the motivation, alongside with the power, to take the initiative to initiate a value embedding effort and to overview the whole value creation process. In the newsprint case, instead, there are several knowledgeable actors, with relatively balanced power and no one really takes a strong initiative, while they all tend to be "steering at each other". The result is that thanks to IKEA's efforts the creation of Lack's low-weight follows a logic of *overall rationality*, which stretches to a network level, whereas newsprint's low-weight follows more a logic of *local rationality*, stretched at best to a dyad.

4) Knowledge politics: Such a powerful actor as IKEA could easily push its own interest in achieving low-weight against those of other actors in the network, such as Swedwood's interest in avoiding risky investments. However, IKEA shows that its interests and those of the network can go hand in hand: IKEA keeps costs low, Swedwood can rely on IKEA's long-term engagement to reduce risk, and carriers' savings can be shared with IKEA. The need for compromise is minimal. In the newsprint case, there are instead several possible conflicting interests that had to be overcome: Hallsta's savings on materials (oil and wood) can turn into a nightmare for printers unless opacity is not guaranteed and ink producers do not make costly adaptations. In this situation there is no mediator for the whole network to ensure a convergence of interests, but there are many local compromises. The Lack case, with its minimal need for compromises around low-weight, presents limited conflicts also on what knowledge to develop and this "steered" knowledge development goes relatively fast, a matter of a few months before the new value feature is embedded in Lack. Instead, the many actual and potential conflicts in the newsprint case require compromising and constant discussions also on which knowledge to develop: thus knowledge grows implicitly, but takes a long time.

5) Knowledge barriers: In the Lack case, knowledge focused on specific resources can hinder other technologies to be developed: for instance, HDF makes it hard for alternatives, such as plastics (that has improved since its original problems) to be considered. Moreover, the goals, but foremost the investments made, block other options to create value for Lack: today the key variable affecting transport costs is no longer weight, but the volume occupied, given today's less weight-sensitive trucks and the focus on achieving full loads. However, the investments made at Swedwood and the current low-weight focus is unlikely to stimulate solutions for a smaller Lack. In the newsprint case, development efforts on some specific features make it hard to focus on others later on. For example, the focus on gaining as much wood out of the pulping process made electricity use less relevant for both the producer and the user. The way disc refiners were designed (with the focus on high wood yield) thus affected the electricity consumption in the process. However, luckily, the steam that is produced during the pulping process could be recovered and used in the paper machine's drying section when oil consumption became an issue to handle. In combination with a thinner paper, the paper mills could save considerable amounts of oil thanks to this. This is an example of how to take advantage of path dependencies that at first look like a constraint.

6) The role of the four forms of knowledge: After having broken down knowledge into the four forms on figure 7 and 8 we can now discuss the role played by each knowledge form and how they interplay in the value creation process, both the value embedding and the value production/utilization. In both cases *conceptual* knowledge initiated resource development. For example, IKEA's calculation identified the problem of high transportation costs, showing the importance of accounting knowledge for developing resources. The development of low-weight newsprint was also initiated by cost calculations showing that higher oil prices would decrease profitability, based on Holmen's accounting system and scenario analysis. Moreover, conceptual knowledge facilitates change by showing both problems and available alternatives, even if the change was more discontinuous in the newsprint case. In both cases *operational* knowledge dominates in the daily value production and utilization of low-weight. The reason is that there is less need to develop or maintain conceptual knowledge in daily routines, but it is more efficient to *black-box* knowledge, make it more operational and not question the assumptions or explanations of why an activity or resource combination is configured in a certain way. In the newsprint case, for example in daily paper making activities there is no time to question the reasons behind the specific grammage weight.

Both cases show that *specific* interface knowledge is needed for developing a particular interface and embed value within it. For example generalized knowledge must be contextualized and applied to well-identified interfaces by Swedwood and Wicoma in order to develop the interface *leg line-empty leg*. The shift between specific and *generalized* interface knowledge is very interesting: in both cases, generalized interface knowledge is present before starting a detailed interface development. In this way, generalized knowledge keeps the search for solutions broad. For example, Holmen started with general knowledge on what a supplier could do with mechanical pulping technology and focused on a specific supplier and its technology, which made it possible to first increase wood yield and then decrease grammage weight. The same did IKEA and Swedwood before betting on the leg line.

In both cases generalized knowledge helps then to diffuse the *utilization* of the low-weight value in new interfaces, that is, in the user interfaces (e.g., with retail stores or printers). Users need in fact to know in *general terms* the potential advantages of low-weight even, just to evaluate this feature, well before they start utilizing it in more specific ways (e.g., by adapting their logistic facilities or their printing presses). Both cases show that when change is going on in the network, there is first a need for generalized knowledge just to evaluate the content of this change and the potentially necessary adaptations (to the lighter Lack or newsprint); but then this generalized knowledge needs to be *contextualized* into specific interface knowledge, both conceptual and operational, in order to fully exploit the advantages of this change by means of specific adaptations in certain interfaces.

To summarize, value creation is sustained by several movements between the two levels and the two types of knowledge of figure 2. All four forms of knowledge play important roles, but they are applied in different moments and for different purposes during value creation:

-*Conceptual generalized knowledge* is important both to identify problems and the *reasons* behind them (e.g., high transport costs because of weight or poor profitability because of high oil prices) and to search and find solutions at a general conceptual level (e.g., let's reduce Lack's weight or let's save paper's inputs): these are all important steps that initiate value embedding episodes. The same form of knowledge is also important to induce users to evaluate the new value-bearing feature, before they take actions to fully exploit it: therefore conceptual generalized knowledge plays a role also to *diffuse* value utilization.

-*Conceptual specific knowledge* is essential in order to make specific calculations on the particular resources that are about to be combined in a specific interface (e.g., HDF and the leg line or specific fibers and disc refiners): thus, this form of knowledge sustains resource development to finding the concrete solutions that conclude a value embedding episode. Later on, conceptual specific knowledge suggests users how to concretely *adapt* their resources to *fully exploit* the new value during value utilization.

-*Operational generalized knowledge* can play a role during value embedding, but only by suggesting quick and ready-made solutions, because outcomes knowledge is restricted to existing recipes and comes often black-boxed (see Latour 1987), so that it cannot suggest *wholly new* approaches. However, this form of knowledge, by its very nature, is absolutely necessary during value production and utilization that need to happen daily and routinely, without the luxury of questioning the causal relations between resources. Such black-boxed knowledge as production facilities is very useful in value production and utilization.

-*Operational specific knowledge* is even more restricted than the above and hence contributes to fixing the final details of an emerging solution during value embedding (e.g., the carving angles of Swedwood's leg line or the interplay paper strength/paper machine speed). On the other hand, this form of knowledge is essential for achieving maximum efficiently during daily value production and value utilization. Operational specific knowledge is often embodied into very specialized machines that handle automatically and with great efficiency only one particular interface, as Swedwood's leg line does.

7. Conclusions, further research and managerial implications

This paper discussed the interplay between knowledge and resource interfaces within value creation. More precisely we investigated how knowledge develops and is applied in the different moments of value embedding and value production/utilization. Value creation involves combining not only knowledge concerning several resources and their interfaces, but also *different forms* of such knowledge. The different forms of knowledge appear with different frequency in value embedding as compared to daily value production/utilization.

The changes in this frequency can be described as movements in the knowledge matrix of figure 2. Moving along the horizontal axis, value embedding was accompanied by a progressive *contextualization* of knowledge, by application to specific interfaces; the opposite movement, *generalization*, was instead visible only in the early value-embedding steps of problem identification or broad search for solutions and in the diffusion of value utilization. As for the vertical axis, daily value production and utilization could only happen after *black-boxing* of knowledge, that is, substituting conceptual knowledge with operational one; instead the opposite movement of *box opening* accompanied the start of value embedding, when many existing interfaces could be questioned.

A value creation process can entail several movements in the knowledge matrix of figure 2, thereby designing more complex knowledge trajectories (see Boisot, 1999, and Boisot & Cox, 1999, for a similar approach in a tri-dimensional space). A value creation process can even encompass several loops starting from any of the four quadrants. It was beyond the scope of this paper to analyze such trajectories but we suggest further research especially about how knowledge trajectories are related to the *configuration* of the network in which they unfold, according to the first 5 indicators on figure 9. Considering the vertical axis, a network with great complexity of technical interfaces and great knowledge dispersion might have problems in black-boxing knowledge for daily value utilization. But the presence of a strong actor (e.g., IKEA) might increase knowledge coordination and help black-boxing knowledge. On the other a strong actor might create barriers against any box opening that goes against its consolidated interests.

Considering the horizontal axis, knowledge contextualization to specific interfaces always risks to create conflicts concerning which particular interface or value-bearing feature to prioritize (e.g., newsprint cannot easily be both lighter and stronger). Compromises can be very time-consuming and induce suboptimal, only locally rational solutions. In such situations, a network with few actors and a clear power structure may be better at setting priorities and achieving solutions rational at overall network-level, through contextualized knowledge. But this very network can become a threat to knowledge generalization, that is, to receiving external influences for value embedding and to developing solutions that can be easily diffused to more general interfaces.

The above are just a few examples of research issues that could be specifically pursued, but that are already visible in our two case studies. For instance, the newsprint case presents complex and indirect technical interfaces accompanied by loose knowledge coordination among many actors, which leads to difficulties in handling several network-level interfaces that can potentially create value: there seems to be too many contextualized pieces of knowledge and it is very difficult to set priorities, also because of conflicting features within the very same interface. The Lack table case shows instead the possibility for a network "steered" by a single actor to handle a handful of interfaces through tighter knowledge coordination of fewer actors: contextualized knowledge is applied to a very restricted set of interfaces for which clear priorities have already been set, also because several actors can draw advantage from the very same value-bearing feature.

This paper also contributes a more nuanced view of the cognitive complexity of the knowledge behind value creation. Reflecting the limits of a firm's "network horizon" (Anderson, Håkansson & Johanson, 1994: 3-4), this paper shows that resource interfaces certainly expand on a single-plane space, so that indirect interfaces between resources "located" farther away from each other are more difficult to discern. However, this paper also shows an additional layer of complexity: resource interfaces are multidimensional and also expand across the several planes of a network. This implies that even within the boundaries of a "small" network, with a fully visible surface, there can be several *neglected* value-related interfaces, either between previously unrelated resources or along previously neglected dimensions. The complexity of resource interactions and combinations (Håkansson & Waluszewski, 2002) entails that *hidden* interfaces can be found well *within* an actor's network horizon or awareness boundary (Dubois, 1994: 127-128), just because this horizon and boundary have a certain depth and is opaque when one tries to penetrate the complexity of resource interactions. In other words, you have these interfaces in front of your nose but you do not really see them.

From the single firm's perspective, creating value imposes the challenge of "choosing" among all the resources in a network, all their interfaces and all their possible combinations. Certainly many "choices" are obliged by the existing physical, social and knowledge investments. Still, many other issues are open for choice and require assigning priorities. The difficulty in choosing resources combinations that enable value creation derives from the need to make choices both statically and dynamically: *statically* means that one simply tries to match the *existing* resource interfaces, locally or at network level, and *dynamically* means that one tries to forge *wholly new* interfaces “on the run”, trying to foresee openings and dead ends. This is a very hard managerial task: because there are external resources involved, it is hard to see value-drivers spread out there, in the network, and because interfaces are multidimensional, it is hard to see value-drivers even if they are in front of your eyes. Therefore, in order to stand a chance in this task firms need to think outside both firm’s boundaries and traditional organizational functions, in order to identify the invisible and hidden interfaces that bear the potentials for creating value.

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