Disassembling Frames on the Assembly Line: The Theory and Practice of the New Division of Learning in Advanced Manufacturing

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Abstract

Car assembly plants have changed dramatically over the last twenty years, after the Kalmar model, lean production, semi-autonomous work groups and kanban. Or have they? By auditing the complex and intertwined learning processes taking place in a brand new assembly plant where the Punto, 1995 European "Car of the Year," is manufactured, it turns out that radical changes in work organizations and operations have been implemented, but their impact stops halfway. The reason is due to the subtle influence that the Fordist "formative context" still exert on the way the plant is designed, and especially the way management knowledge is divided. By analyzing how bottlenecks and breakdowns are tackled by operators and managers, it is shown how the new division of labor requires a rethinking of the kind of know-how operators should master in order to cope with an advanced production system. The paper includes two important tools that were used during the analysis: a conceptual model of the learning organization, called the learning ladder, and the main steps of the learning audit methodology.

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1. INTRODUCTION

Traditionally, changes in work organization have been carried out relying on the analysis of procedures, data flows, activities, "objects," transactions and processes, assuming that "work" can be ultimately decomposed in such constituent elements. Technology is then harnessed to streamline processes, make transactions more efficient, and better govern and store data flows (Davenport 1993). However, the study of situated work practices has pointed out, in a variety of office and manufacturing settings, that work is more than a bunch of analytical abstractions and models to be rationalized (Wynn 1979; Suchmann 1987; Brown and Duguid 1991; Zuboff 1988). Rather, it is a complex bundle of situated actions and interpretations aimed at making sense of resources and structures, and maintaining the identity of the members and the working community confronted by both routine and breakdown events. One important design challenge that remains for specialists, users and scholars today is to identify the role of information technology (IT) in supporting work, understood according to those perspectives which emphasize the crucial role of human action and interpretation (Barley 1986; Winograd and Flores 1986; Orlikowski 1992; Walsham 1993; Ciborra and Lanzara 1994; Boland, Tenkasi and Te'eni 1994).

We tackle this challenge in the light of Zuboff, who suggests that the design of computer-mediated work should be centered on the idea of learning as "the new form of labor": "The informated organization is a learning institution, and one of its principal purposes is the expansion of knowledge...knowledge that comes to reside at the core of what it means to be productive" (Zuboff 1988, p. 395). This perspective requires the development of an appropriate methodology, as the existing ones are oriented to data flow, decision making or transaction analysis. In short, we need a "compact" way to understand how learning is typically divided in a firm. Our study must clearly be of an interdisciplinary nature, since learning processes have been the subject of recent economic literature (Nelson and Winter 1982; Williamson 1985); sociology, anthropology and social psychology (Argyris and Schön 1978; Lave and Wenger 1991); and management literature (Huber 1990; March 1991; Fiol and Lyles 1985). In particular, recent studies in the resource based view of strategy (Grant 1991) and structuration theory (Giddens 1984; Orlikowski 1992; Walsham 1993) can improve our understanding and be a new platform for work and systems redesign.

In our perspective, the processes through which resources and routines become part of the core capabilities of the firm and of its structure should be looked at as the key learning "tasks" carried out by members of the organization from the shopfloor to top management (Andreu and Ciborra 1994).

A new methodology should identify the key processes of knowledge production (Nonaka 1994) and accumulation in an organization, their inefficiencies, and point out how IT can meet the needs for improving the existing division of learning. We develop and apply such a methodology, called "the learning audit," while evaluating work design and patterns of computer usage in one of the most advanced car manufacturing plants in Europe: Fiat's Melfi car factory. This factory features a lean production organization; work flow based on assembly lines and teams; advanced applications of IT to production management and control; and extensive reliance on total quality management. Since our study was carried out during the first year of operation of the green-field plant, we could observe in detail how the new organization was performing in facing a variety of minor and major breakdowns, by enacting different sorts of problem solving, computer-mediated communication and learning strategies. We found that the cognitive and information resources that support the division of learning in the new plant were not fully appropriate and that, as a result, the traditional assembly line concept (or formative context [Ciborra and Lanzara 1990]) still exerted a subtle, far-reaching influence on the interpretive schemes and organizational routines applied by workers and managers in the Melfi factory. In positive terms, we could also identify new frames and new routines (i.e., the new formative context) needed to better run the process, intervene in breakdowns, use IT and learn.

In section 2, we present a model of the firm as a learning organization, called the learning ladder. The model draws on key ideas of the resource based view of strategy and, in part, from the theory of structuration. The "learning audit" methodology is briefly described, in section 3, as a way of capturing the dynamics of the learning processes identified by the learning ladder. In section 4, the case of the *avant garde* plant is presented, where the learning audit methodology has been tested. In section 5, the results of the analysis indicate the points of failure of a few, main learning processes dedicated to the control of breakdowns and bottlenecks. The analysis further suggests what interventions (both technological and instructional) would be needed to ameliorate the lean manufacturing operations. More general conclusions on cognition and the organization of work in advanced manufacturing follow.

2. THE LEARNING LADDER: A MODEL FOR THE LEARNING ORGANIZATION

In any economic organization, there are a variety of learning processes at work. For example, in highly situated ways, people learn by doing (Williamson 1975; Nelson and Winter 1982); they learn by using systems and technologies (Rosenberg 1982; von Hippel 1988); at times, they engage in double-loop or radical learning (Argyris and Schön 1978); and, more generally, they are busy creating new knowledge by socializing the results of learning and converting explicit into tacit knowledge and vice versa (Nonaka 1994). Our aim is to build a "compact" model of the main learning processes in an economic organization. Such a model is useful as a "backbone" reference scheme for investigating strengths and weaknesses of actual learning processes.

To begin with, consider the recent strategy literature, specifically the resource-based view of strategy. At the heart of the firm's competitive strength is a process that develops distinctive, core capabilities (Prahalad and Hamel 1990), i.e., capabilities that differentiate a company strategically and deliver competitive advantage (Leonard-Barton 1992; Barney 1991). Core capabilities develop through a fundamental *transformation process*, by which standard resources available in open markets (where all firms can acquire them) are used and combined, within the organizational context of each firm, to produce capabilities, which in turn can become the source of competitive advantage, especially if they are rare and difficult to imitate or substitute. We look at such a transformation as a *situated learning process*, i.e., a learning process whose unfolding is highly contingent upon the interaction among people, resources and routines present in a given situation. Situated learning plays a strategic role for the firm because (1) it implies path — dependency and specificity in the resulting core capabilities, and (2) consequently, it causes their inimitability, a crucial characteristic for obtaining competitive advantage. In order to build our model of the learning organization, we propose to analyze in more detail the major stages of the learning/transformation process through which the firm's core capabilities are generated.

A first step in the transformation consists in the emergence of generic capabilities from standard resources (see Figure 1).

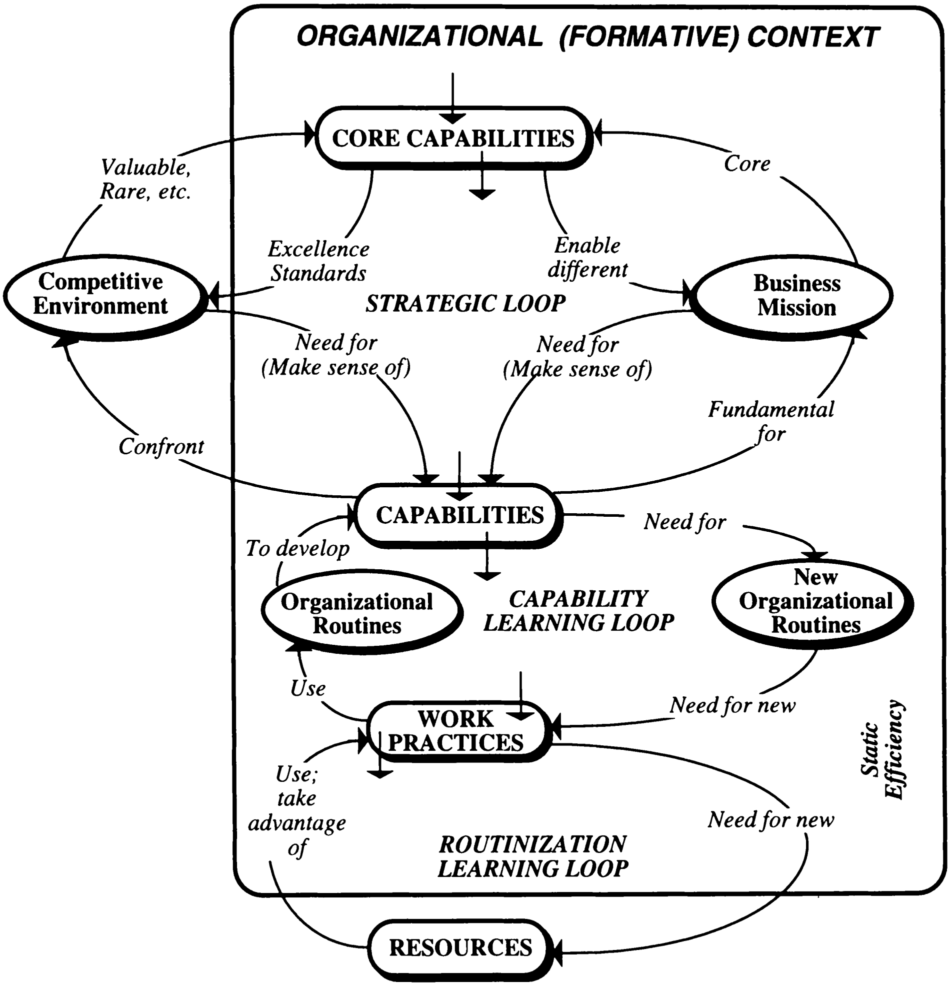

Figure 1. The Learning Ladder

Two different types of learning take place at this stage. One deals with mastering the use of standard resources, and produces what we can call efficient work practices (Lave and Wenger 1991). Individuals and groups (or communities of practice) in the firm learn how to use resources in a given organizational situation. The quest for better work practices may trigger a search for new resources, more appropriate to the practices under development. Or, the appearance of new resources (say technological innovations) may motivate individuals and groups to "take advantage of them" through new work practices. We call such a learning loop between resources and work practices the *routinization learning loop*, since its outcome are repertoires of constrained, routinized and interdependent actions (Pentland and Reuter 1994). Mastering the usage of a spreadsheet by an individual or a team in a specific department is an example of this type of learning.

A second learning process "abstracts" capabilities from existing work practices. Several characteristics connote this learning process: it involves combining emerging work practices and organizational routines; its outcome has a strong potential connotation, as capabilities convey knowledge which can be put to work in a variety of organizational contexts (non-situated knowledge). That is capabilities are more abstract than work practices: they are "skills without a place" that can be transferred across the organization (such as a quality control capability). Finally, capabilities can be easily described in terms of *what* they do and *how* they do it, but *why* they do it is taken for granted, not necessarily well defined and rarely challenged. We call this the *capability learning loop*. To summarize, learning at this level results in a continuously improving set of capabilities — specialized and idiosyncratic ways of using resources for given purposes. These purposes are functionally well defined and stable over time (e.g., cutting production costs), although how they are attained may change drastically, for example with the emergence of a radically new technology (resource), or a revolutionary new use of an old resource (Penrose 1959). The driving force for continuous capability improvement is static efficiency (Ashby 1966; Klein 1977; Ghemawat and Ricart 1993). Such learning processes tend to occur spontaneously, but the organizational climate and context, the incentive, power and motivational systems, and, last but not least, the technology are ultimately responsible for the learning styles that can be observed in different organizations.

At a higher level, capabilities can evolve into core capabilities which differentiate a company strategically (Grant 1991). There are two main elements against which capabilities can be checked for their potential to become core: the competitive environment and the business mission of the firm. When faced with its competitive environment, a firm learns whether some capabilities have strategic potential (they are valuable, rare, etc.). A converse influence, from core capabilities to capabilities, also exists through the competitive environment, as (1) core capabilities of different firms competing in an industry define the "standards of excellence" for that industry. Hence, they can elicit which capabilities a firm should develop in order to compete effectively. (2) It is when confronted with a given environment that capabilities acquire a sense of *why* they are important: we are in the realm of dynamic efficiency (Klein 1977). For example, changes in the environment can make a highly efficient (in the static sense) capability worthless, because it is useless for competing under new circumstances (Langlois 1985).

A firm's business mission is also relevant for identifying the core capabilities, since it sets priorities in the alignment between them and the current mission. In turn, core capabilities can enable new business missions which, if accepted, may trigger new "capabilities — core capabilities" transformations. These interrelationships are captured by the *strategic learning loop* which links capabilities and core capabilities.

The environment in which learning occurs is an organizational context, which influences the learning process and is in turn influenced by its result (i.e., new working practices become part of the context, thus increasing the knowledge base of the organization [Giddens 1984; Orlikowski 1992]). Such an organizational context has the characteristics of a formative context (Ciborra and Lanzara 1990).[1]

Also, the strategic loop takes place within the firm's organizational (formative) context and so it is "structured" by it. In turn, its outcome — core capabilities — can reshape the context itself (Giddens 1984). In this respect, consider the role of organizational inertia and the limits to learning (Argyris and Schön 1978; Kim 1993). To drastically change the context in which learning takes place is a difficult endeavor, although sometimes necessary — for example, in order to respond to radical shifts in the environment and/or business mission. However, drastic changes in the business mission are not likely to occur, as its definition and meaning correspond closely to a given organizational context. Revolutionary changes in organizational context or business mission require radical learning, i.e., becoming aware of what the context is and explicitly stepping out of it in order to innovate (Argyris and Schön 1978).[2]

3. THE LEARNING AUDIT METHODOLOGY

Learning occurs through situated knowledge creation and accumulation processes. The learning ladder indicates that knowledge is created on four different levels: routines, capabilities, core capabilities, and formative context. The learning audit methodology is aimed first at evaluating the effectiveness of each learning loop. Specifically, we look at how people at work engage in individual and collective actions and reflections, which lead to the transfer of existing knowledge and the production of new one. Starting from the assumption that knowledge is embodied in praxis (Pentland 1992), we have operationalized our theoretical framework by means of a qualitative/inductive methodology. In other words, we conduct an ethnographic inquiry on the learning processes of individuals and work teams based on participant observation and a "thick description" of everyday practices and routines (Geertz 1973). The methodology elicits from the surface content of objects and behaviors the implicit beliefs embodied in them. It uses grids as

[1] A formative context is defined as "the set of preexisting institutional arrangements, cognitive frames and imageries that actors bring and routinely enact in a situation of action" (Ciborra and Lanzara 1994; Unger 1987). It comprises both the interpretive schemes and the organizational routines that influence problem solving in organizations (Dougherty 1992). However, the explicit reference to the notion of context points out that a formative context shapes routines and frames: it is their background and active mold. Learning new routines is a single-loop process. Restructuring a context implies double-loop learning (Argyris and Schön 1978).

[2] In this paper, we omit the analysis of how the learning ladder is situated in the broader social context, i.e., how does learning within firms contribute to changes in the broader social context and, conversely, how broader social institutions shape the ladder (Powell and Di Maggio 1991).

guidelines which provide a general framework for observation and interviews (see Tables 1 through 4).

Table 1. Where is Knowledge Situated? Flows and Systems

FLOWS & SYSTEMS	EVIDENCE
ORGANIZATIONAL STRUCTURE	organizational units, tasks and roles
WORK FLOW	production cycle, work operations, production lines
INFORMATION SYSTEM	e-mail, computerized production control, "radar" system
QUALITY CONTROL SYSTEM	quality control procedures, quality indicators and certificates

Table 2. Where is Knowledge Situated? Actions and Events

ACTIONS & EVENTS	EVIDENCE
MEETINGS	analysis of interaction patterns, language, idiosyncracies, attitudes
COACHING	analysis of transferred values, skills, behaviors, coaching styles, attitude toward errors
INFORMAL COMMUNICATIONS	face to face interaction, conversations
BREAKDOWNS	local case phenomenology
WORK PRACTICES	organizational routines, rituals, patterned activities
LEADERSHIP STYLES	language, gestures, management of individuals, groups and resources, leader background

Table 3. Where is Knowledge Situated? Objects and Artefacts

OBJECTS & ARTEFACTS	EVIDENCE
VISUAL CONTROL TOOLS	notice boards, panels on the line, kanban, error messages
ORGANIZATIONAL MEMORIES	anomaly cards, problem solving procedures, customer feedback diaries, informal memos, charts
ORGANIZATIONAL SYMBOLS	writings, signs, metaphors
WORK TOOLS	machinery, equipment

Table 4. The Learning Outcomes

Learning Loops Observed Items	ROUTINES	CAPABILITIES	CORE CAPABILITIES	FORMATIVE CONTEXT
FLOWS & SYSTEMS				
ACTIONS & EVENTS				
OBJECTS & ARTEFACTS				

The study concerns two levels of analysis. The first level addresses the issue: "Where is knowledge situated?" Specifically, it observes relevant events, visible behaviors and artefacts, and the organizational action system, i.e., how people interact in and with the situation. We selected features of a situation, such as flows and systems, actions and events, objects and artefacts, which constrain or induce intentional performances or at least fall into the scope of attention of the actors in the situation. The situation sets the stage where people engage in processes of interpretation and sense-making (Daft and Weick 1984). Thus, two types of phenomena stand out: observed behaviors and interpretations provided by the actors. The second level deals with the "institutional" dimension of knowledge (Douglas 1986). Its purpose is to trace back from the observation of visible behaviors and artefacts, the "theories in use" (Argyris and Schön 1978) or interpretive schemes (Orlikowski 1992) informing them, together with the organizational routines and contexts that shape them. The framework in which action takes place consists of specific institutional arrangements and the stock of background knowledge (formative context) which actors take for granted. Such a context emerges only in situations of breakdowns and critical circumstances, when the obviousness of daily routines becomes problematic. The actors' perceptions and interpretations can also be integrated with the concepts inferred by the researchers. Table 4 shows the main items which should be collected in the field for this purpose.

The study, which included the test of the learning audit methodology, was conducted during 1994. Data was gathered during six one-day visits to the plant and a five day period of immersion in the work environment. Thirteen people were observed while they were working in the plant and interviewed at their workplace. They included a variety of profiles ranging from generic workers to those responsible for the work teams and managers of various functions. Twenty hours of interviews were recorded on tape. Additional informal conversations took place throughout the plant and were not recorded. Four meetings were held as group interviews with production and systems managers. After the first report was delivered, three further meetings were held with the same group of managers to discuss and validate the results.

4. THE MELFI PLANT: FROM TOTAL AUTOMATION TO THE "INTEGRATED FACTORY"

The Melfi plant produces the latest Fiat model, the Punto, today the best selling car in Europe. The plant can assemble 1,600 cars a day (450,000 per year) at full production speed, employing 7,000 people on three shifts. The factory, situated in the south of Italy between Naples and Bari, is a "green field" site, set up at the end of 1993 and, after an experimental phase, opened officially in October 1994. Inside the Melfi industrial district are the plants of sixteen suppliers. Their location, close to the main assembly plant, makes possible the reduction of suppliers' lead times. Lean production and, in part, Just In Time (JIT) are applied as methods to organize the work cycle. The workforce belongs to a homogeneous cultural and geographical background. Workers, managers and employees are young and mostly from the south, often at their first job. The core group of first-hired workers is composed of skilled personnel with a good level of education (engineers or high school degree). The local identity is quite strong: they are highly motivated with a great sense of pride and enthusiasm (the region where the plant is located, like the rest of the south of Italy, has very high unemployment).

At the beginning of the 1980s, Fiat embarked resolutely into the so-called high-tech factory concept, which privileged intense automation to yield high productivity and quality, while reducing the role of human work drastically. Results, however, were deceptive, and the lessons learned from "lean production" (Womack, Jones and Roos 1990) have led to the implementation of a different strategy. The Melfi plant is the first example of the new production concept adopted by Fiat in the 1990s: the *integrated factory*. The apparent shift from automation to integration was due to management's newly acquired awareness that quality cannot be the outcome of a sophisticated technology only, with little involvement of the workforce. The new philosophy of integration tries to reconcile a high-tech infrastructure and the rigid synchronization of the assembly line with elements typical of the job shop (such as working in teams). To use an analogy, as in the building industry, the finishing jobs are entrusted to skilled carpenters in order to increase the added value of the building. Today, for the finishing work on a car, one relies much more on human work, rather than sheer automation, in order to raise the *quality* of the final product. Integration means *tighter coordination* through a variety of means. The great amount of paper as a means of communication, the highly sophisticated production and control information system, the frequent meetings and face to face interactions support the multiple facets of both formal and informal coordination. On the other hand, the distributed capability of managing breakdowns and problem solving, the importance of intuition, the coaching/training routines based on imitation emphasize the key role played by human resources and the presence of a capability for improvisation and bricolage. Such a capability is typical of *craftsmen*. The workers are able to react to the frequent breakdowns without going into a panic (Weick 1993). The action-centered skills ("fire fighting," "hands on" attention of the workforce) and the role of the "body" seem to prevail upon the intellectual skills and the capacity to abstract from action (Foucault 1980; Zuboff 1988).

4.1 The "Crystal Pipeline"

The factory is divided into four operating units (OU) responsible for the different stages of the production process: Pressing, Body Welding, Painting and Assembly. The four OUs cooperate in defining the daily production plan, monitoring the advancement of production, and managing the critical situations/problems. The longer term production plans are defined in Fiat's head office in Turin (in the north of Italy). The production process can be described as an incremental one. The essence of the process is to build the car *bit by bit* by having workers perform the same task on each car as it moves through their workstation on a conveyor system. The average time for each operation is about thirty seconds per car. Inside the Assembly unit, most of the tasks are performed by workers, while the other units are almost completely automated.

Each OU is divided into a number of UTEs (Elementary Technical Unit). The UTE, which comprises from twenty to forty workers and supervisors, is the basic production structure of the integrated factory. It can be defined as a semi-autonomous work team that manages a technical subsystem with its distinctive product and production process. Specific objectives and results are assigned to each UTE such as productivity, quality, budget, mix, and quantity. A UTE has a leader supported by a staff of technical specialists for maintenance tasks (the "technologists"). Typically, a UTE controls one or more production lines that are split into a varying number of workplaces occupied by one or two workers (or robots in the automated OUs). The number of workplaces depends on the number of elementary operations that have to be carried out in order to complete a given production sequence. UTEs also have a small "office" (often located alongside the line), which can be considered an information point, and a work group base. Here we find desks, PCS, terminals, and a number of notice boards that contain different signs and charts. The UTEs report to other management functions (Production Engineering, Quality, Personnel, etc.) from which they receive guidelines, and instructions, so they are not in a position to close the feedback loop (i.e., to influence the choices of these functions). In other words, a UTE is expected to solve (or contribute to solving) all problems that may hinder production, to control many quality aspects, but it cannot contribute to the overall development of (or have an explicit influence on) its immediate environment. UTEs can be seen as self-contained minifactories managing a whole segment of the production process. The modular organization fosters fluidity and integration of production processes and ensures a high degree of flexibility. The various units composing the organizational structure are linked according to a *customer-supplier model*, which means that each UTE must think of the next process as its "customer." More generally, the whole production system is organized as a customer-driven market, in which activities are structured as a network of flows and transactions between semi-autonomous units. The lean production logic implies producing only the amount required by the customer, at high quality, at low cost, and at the time needed. The production lines are organized in a way that allows every work place (and therefore UTE) to receive and pass on a "finished product" that can be judged for its quality. Bonazzi (1993) has described the integrated factory model by using the metaphor of a "crystal pipeline." The pipeline represents the continuous flow as it was originally conceived: a simple, linear structure in which work-in-process flows. The pipeline is open to market demand and the work flow is structured through a rigid orders schedule which is imposed from Fiat headquarters according to the production mix required by demand.

The image of the pipeline that portrays lean production indicates a rigid synchronization of all the processes occurring inside it and a high level of collaboration between the different units. But the pipeline is made of crystal, material that evokes the idea of transparency and fragility. Transparency means first eliminating waste and defects. Second, avoiding informal stocks and slack, and thus curbing shirking and other forms of opportunistic behavior. Third, making all available knowledge explicit: work is made transparent and "textualized" (Zuboff 1988) by representing all relevant aspects of the work flow through the *visual control system* (see below the "radar system"). The fragility of the pipeline is related to the rigid synchronization of the work flows and to the lean production concept. Since bottlenecks and the piling up of inventories can disrupt the flow and break the pipeline at any moment, everything in the plant has been synchronized with the purpose of avoiding bottlenecks, work-in-process inventories and buffers.

4.2 Breakdowns and Bottlenecks

In the best of all worlds, the line never stops. Unfortunately, the lean production concept is a source of unexpected and risky events. In fact, this concept is associated with a complex system of relations which is not always possible to fully control. At any moment, the mechanical synchronization of the operations can collapse for various, unpredictable reasons: absence of supplies, machine breakdowns, human errors, and so on. As the line stops, work-in-process piles up quickly, bottlenecks may emerge, and UTEs can be kept on hold, unless they intervene. In some cases, the causes of bottlenecks can be very complex, since they are related to the constantly changing product mix and not to a specific breakdown. That is, even if the factory as a whole might have enough capacity, there may be a mismatch between the line balance and the product mix being pushed through. Such bottlenecks highlight the key role of capacity planning (Schmenner 1990).

Bottlenecks are the most frequent manifestation of both local and systemic breakdowns. At the end of each line, there is an inventory where the car bodies, waiting to pass to the next process, are stored. These inventories can be seen as buffers. If a line stops as a result of a breakdown, the upstream processes keep going until the inventory closer to the problem is full. At this point, a bottleneck arises and the upstream lines must be stopped (thus creating work-in-process inventory). The downstream processes, in turn, stop receiving cars and, once their upstream inventory is emptied, they must be halted too. When the problem causing the bottleneck is solved, the line is able to receive the bodies and the flow can restart. If it is solved before the formation of bottlenecks along the line, it will remain at a local level. Otherwise, it will affect the whole system. The longer the duration of the halt, the higher the number of parts accumulated and the imbalance created to the flow.

In car manufacturing, the main *sources of bottlenecks* can be caused by process/product anomalies, line imbalance, machine breakdown, lack of materials, quality problems and lack of workforce (Suzaki 1987).

But bottlenecks may also have a more "abstract" origin related to problems of coordination, of which capacity planning is one. Another is due to the opacity of human behavior, to the tendency to focus on individual interests and to "manage one's own position" (Senge 1990). For example, the customer-supplier concept implies that UTEs coordinate activities between them as transactions between semi-autonomous units (Williamson 1985). In this "coordination game," instances of "local suboptimization" and opportunistic behavior may arise; that is, activities are executed in order to optimize a given UTE's performance rather than the overall production. In turn, local suboptimization may lead to the build-up of inventories along the lines. Often opportunistic behavior may be fostered unwittingly by a company's values. For example, in Melfi, *quality* is a pervasive concept crossing all production processes and is displayed through multiple organizational artefacts. Quality is both a *technical requirement* (absence of defects; reduction of waste and demerits) and a *cultural value* (responsibility; collaboration; commitment and motivation; identification with the customer, the product, and the company). In order to "measure" it, quality has been defined in terms of "demerits" (i.e., number of defects). The demerits system sets visible targets for continuous improvement and enhances the level of care and attention to the product and the process. However, as each demerit is ascribed to a UTE (or better, a work station), which is supposed to be at the origin of that demerit, the negative measurement may be perceived as a punishment and be frustrating for particular individuals and UTEs. The demerits system, possibly inherited from the conventional Fordist model, may represent a barrier to the achievement of full transparency of behaviors, since it induces workers to enact defensive behaviors, face saving, scapegoating and other tactics that ultimately interfere with effective problem solving and learning (Argyris 1993).

Finally, bottlenecks can be traced back to the coupling between the sheer complexity of the production system and the actors' bounded rationality. The new assembly line and the system of exchanges between customers and suppliers can be compared to a network of concurrent events, which is impossible to fully control, as opposed to the traditional, sequential assembly line. Sometimes a corrective action performed in one point of the system can generate a problem in another (distant) station along the line. As the complexity of relationships between different processes is very high and cannot be properly handled, bottlenecks can be generated unknowingly as a result of a lack of "systems thinking" (Senge 1990). To conclude, bottlenecks represent opportunities for problem solving and learning. Effective intervention requires an ability to discern their sources and causes, lest corrective routines are adopted that may lead to further propagation of mistakes and disruptions, and to very little learning.

5. THE MAIN FINDINGS

In what follows, we report the analysis of the learning processes observed in connection with a variety of breakdowns and bottlenecks, using the four main levels (learning loops) of the learning ladder presented in section 2. A first empirical finding regards the discrepancy between those problem solving procedures which are successful, and lead to higher levels of learning and competence building, and those interventions which are less successful and do not contribute to any further learning or competence enhancement. A second finding is that the same problem solving routine is applied to most breakdowns along the line, no matter what their cause. Data collected on the learning loops allowed us to identify the reasons for which workers and managers were showing good levels of competence and learning when dealing with certain situations, while they were not so competent in other circumstances, typically when system-wide disturbances occurred. The learning ladder shows that the origins of such discrepancies lie in the formative context that has subtly influenced the design and implementation of the Melfi plant. The same model, coupled with the audit methodology, can point out the positive reforms that could be introduced in management and worker training programs and information systems design, in order to increase the variety of the problem solving repertoire and help change the extant formative context. We present the findings by describing first the generalized problem solving routine that is applied daily throughout the plant. Next, we consider the different situations for which the routine in question is more or less effective. Then, we look at the cognitive and organizational dynamics of the main learning processes related to the application of the routine. Finally, we suggest a number of interventions to address the failures of the learning processes.

5.1 Trouble-Shooting in Melfi

The problem solving routine most frequently observed in the plant operations is based on an incremental feedback model. Whatever the breakdown, the routine seems to consist of the following "moves" (Pentland 1992):

- "see " a problem (e.g., building up of work-in-process inventory);
- mentally "search" for the station where the cause of the problem may originate, based on the previous knowledge of past bottlenecks; work stations and relevant operations characteristics; information received or gathered from other points on the line;
- "go to" the station held responsible for the breakdown, or communicate with operators there (depending on proximity of the station);
- "disassemble/re-assemble" a part or a component of the car or the production machine in order to fix the problem;
- register intervention and solution for future memory;
- take care *ex post* and on *ad hoc* way of inventory pile-ups or stock outs as minor side effects to be fixed (since the main cause has now been dealt with). If such side effects persist, wait for the flow to settle down to the normal pace of operation (no significant learning seems to take place at this stage).

The striking characteristics of such a problem solving procedure, which we have called the "Disassembly/Assembly" (D/A) problem solving routine, besides its "routinized" or repetitive nature (Pentland and Reuter 1994), are its ubiquity, concreteness, "situatedness," and high consistency. Namely, we found instances of its application even in areas distant, at least conceptually, from the car manufacturing process: *"When we started to work in the new plant, we didn't even have desks for the UTE's offices.* We built them *with pieces of iron that were laying around*" (Head of UTE A). Problem solving must be concrete, "hands on" a machine. *"It is more effective to hold a meeting in front of a problem than in front of a desk....To start reasoning in front of a drawing is one thing. To be directly in front of the machine is a totally different thing....We need to transfer the problem* [solving procedure] *from the desk to the operations point....We need to work as a team in front of the problem* [the machine]" (Head of UTE B). And, although a strong need for a "global vision" of the production flows is strongly needed, the way suggested by the UTE's leaders as to how to acquire such a vision is pretty concrete: *"We convey a global vision by having workers learn something new all the time through job rotation. The worker acquires more confidence with different production phases and operations....He learns to "see" new things and gets a global vision of the process*" (Head of UTE C).

The computer-based information system reinforces this way of solving problems. In each UTE's office, a PC shows screens which portray the relevant segments of the production lines, listing for each work station the number of semi-finished cars entering and exiting the station, together with the levels of in-process-inventories. Other screens offer the data in a more aggregate form, identifying the quantitative flows between UTEs. The same network feeds into the big electronic boards (the so called "radar" system) which show production data for each UTE and all the related alarms. The radar boards reproduce at a higher level the idea that you have to "*see*" and "*feel*" a problem in order to make it "*really true*," and amenable to a "go to" and "hands on" solution.

Finally, the routine allows for variations, although within the boundaries set by the D/A metaphor. At a cognitive level the whole production process is perceived and thought of as a sequence of operations. Although sometimes knowledge of the global process is necessary to solve "local" problems, or take care of the ramifications of local breakdowns, the procedure followed consistently implies the decomposition of global problems into lower level ones, capable of being resolved through a local D/A intervention. We have observed various instances when a breakdown occurs, or a bottleneck is perceived, in which the worker or the supervisor goes back mentally through the working cycle and through a *gedanken* experiment disassembles the car in order to search for and identify the potential source of the default, i.e., what *operation* might not have been carried out in the proper way. It is implicitly assumed that the source of the default is always unique. If the mental and physical search is successful the problem is visualized, a local intervention is proposed, tried out and learned: [background noise; line-stop alarm ringing because of an inventory build up] "It's four screws. You slam it down, re-screw and streamline [the body of a car]. *You know it better than I do! It is just four screws!*" (Head of the UTE A to a technologist). To conclude, an analogy emerges between the *physical* layout and workflow in the integrated factory, and the *cognitive* strategies present in the problem solving routines. The way operators think is linear and sequential, thus reflecting the organization of the physical flow of cars along the line.

5.2 Mixed Success

Our empirical observations of breakdowns and the ways they are tackled indicate that the D/A problem solving routine works efficiently for the large majority of technical breakdowns occurring along the lines. That is, workers have acquired and internalized the procedural skills and competencies necessary for dealing with most breakdowns. As wished by Fiat's new vision of the integrated factory, workers in the Melfi plant appear to be "smart artisans" and good "mechanics," able as "bricoleurs" to make effective use of the resources available in their work environment. We noticed, however, situations during which a lack of competence seemed to emerge at various levels of the organization, starting from the lower ones. In general, such situations are related to the build-up of in-process-inventories. Their causes are often of a "second order" nature. They may stem from local sub-optimization strategies carried out by some UTEs, or unintended side-effects due to the application of a local D/A routine to fix a problem somewhere along the line, or "systemic" causes linked to the production mix, capacity load, etc.

Picture two sharply different scenarios: A proactive one, where for disturbances for which a "local" cause, whether real or imagined, has been figured out, and the worker "sees," "goes to" and "intervenes hands on"; and a passive one where, in the face of systemic breakdowns, workers simply wait for the line to restart. In the latter scenario, although a line stoppage and the ensuing waiting time are regarded as a form of waste within the lean production context, we found that it was an accepted behavior "to take a break and smoke a cigarette" if an inventory pile-up occurs for which causes cannot be easily discerned and fixed locally. But it is not only a matter of line slow-down or stoppage. Learning is impaired too. The linear mental map of the assembly line, seen as a rigid sequence of operations, does not work as a cognitive resource at hand for effective problem solving. On the other hand, no appropriate mental map of the concurrent events which lead to the stochastic in-process-inventories is available throughout the organization. Hence, there is no ground on which to accumulate knowledge about how similar problems have been solved previously. Instead of learning, then, and competence building, a conviction takes over whereby the complexity of the process overwhelms the decision makers. Bottlenecks seem to pop up in an unpredictable way ("*Every day there is something new happening*"). They seem to require always new, *ad hoc* solutions ("*Bottlenecks do not happen to have always the same solutions*"), or choosing between doing nothing or applying the D/A routine, just to "keep busy" in front of the unknown (Weick 1993). The generalized D/A routine is consistent with both the concept of the "mechanical," rigid sequence of operations on the traditional assembly line and the role of the worker as a mechanic-bricoleur. However, the lean production concept as applied in the Melfi plant generates an integrated, dynamic system connecting interdependent stations, which have a certain degree of autonomy in carrying out operations (the customer-supplier model). The repertoire of problem solving routines should be molded to a great extent by the latter design concept, too. But this is not the case. Why?

5.3 The Learning Ladder Unveiled

We believe that the D/A routine is so powerful in shaping problem solving and learning throughout the plant, because it embeds the "archetype" of mass production, and the assembly line in particular (Greenwood and Hinings 1988). The D/A metaphor appears to have been transferred almost intact from the slaughter houses in Chicago, where Ford had the first idea of the assembly line, to the *avant garde* plant in Melfi. Based on our interviews, we suggest that such a transfer occurred during the one-year long, intensive training period (carried out in the old assembly plant of Mirafiori in Turin), where the capabilities of the future workforce were developed and fine-tuned, especially during the hands-on sessions that included building off the line a real car "bit by bit." *"A smart idea during our basic training was to disassemble, re-assemble and disassemble again and again a few cars. Can you imagine? These cars are still laying around somewhere in the new plant"* (Head of UTE A). The D/A metaphor stays at the heart of the "assembly line" formative context and exerts a strong influence on the vast array of learning processes which take place in the plant. Here, the learning ladder can reveal how pervasive this influence is:

- *work practices*, both individual and team based, are aimed at building the car, or deconstructing it in case of breakdowns, bit by bit;

- *capabilities*: the D/A work practice becomes a generalized problem solving capability in use across the whole plant. It is applied to whatever problem emerges along the line. Where distance impedes a direct presence "in front of the machine," appropriate communication and information mechanisms are set up to handle the problem in a distributed way, while preserving the basic approach;

- *core capabilities*: the strategic value of quality of the final product is also supported by the D/A capability. For one thing, analytical attention to the detail is paramount to the implementation of quality management throughout the plant ("*Quality is there in the smallest assembly operation....Quality is not something pompous; it is doing things well according to the rule, and doing them in the same way over and over again*" Head of UTE B).

- *the formative context*: Ford's concept of the assembly line is very much alive in the design of the new plant. It is present in the split between task execution and task directional, though in a modified form, whereby all knowledge necessary to carry out D/A operations is widely distributed, so as to support the partial self management of each UTE and the coordination between them. However, production planning and control and, more generally, a systems view of the flows remain with a few functions at a higher level.

- the *computer-based information system* is designed to convey and register all the quantitative data regarding actual versus planned production, with the smallest detail for each work station along the line.

The consistency found along the learning ladder, and in the information system that supports it, has both strengths and weaknesses. Namely, the learning audit points out that accumulation of knowledge which fits the basic metaphors and practices embedded at the various levels of the ladder takes place smoothly. In other words, problems involving fixing the car along the line are solved with dexterity and speed; solutions are stored and made accessible for the work teams; artefacts are available to capture in written form such solutions and the network infrastructure is used to communicate in relation to such activities. However, problems which do not fit the existing formative context are dealt with in a much more nebulous way. No cognitive maps, individual or shared, help the operators to represent the disturbances and identify a solution space, and even less to store the causal links between errors detected and problem solving routines. Hence, no memory and competence are built up; learning does not take off from the *ad hoc* work practices, and capabilities are not generated. On the other hand, the formative context which enforces the separation between task execution and task direction prescribes that knowledge (frames, routines, know how) be relegated to those specialized and managerial functions, which deal with the design of the plant, its computer system and the management and control of production (following, then, the principles of Scientific Management [Taylor 1911]). The audit highlighted a strong departmentalization and hierarchization in the way production management knowledge and learning were divided. For example, only those specialists in Turin, who designed the Melfi plant, knew the simulation programs for capacity planning and the flows layout design. These programs were developed by a separate subsidiary. The Production department did not use the simulation programs, and only a few managers of the plant were taught scheduling programs. Finally, line managers did not have enough resources to go beyond troubleshooting and firefighting when bottlenecks occurred. All this reinforces the following conclusion: the old and the new production concepts clash with one another, despite attempts at reconciling them in the original design of the Melfi plant and operations. The old kept task direction strictly separated from execution, but endowed it with resources (production programmers and managers). The new concept, instead, delegates part of decision making and problem solving to the UTEs and, at the same time, subtracts resources from the managerial structure (aiming at a leaner organization). The audit shows that the learning ladder regarding the control of complex production events is consistent with the old concept. Hence, distributed learning about the management of production flows is not obtained. The widely available network infrastructure does not help either, since the systems do not support the running of any simulation of the production flows. They compute inputs and outputs for each work station, but not rates, flows, and probabilities data that would enable UTEs' members to simulate on their office PCS the potential consequences of their interventions at a plant-wide level.

5.4 Some Redesign Suggestions

A number of positive design ideas have emerged from our study. First, we recommend that exposure to the concepts of systems dynamics could be a way for UTEs' members to learn more effective strategies to cope with complex breakdowns and bottlenecks. Second, learning new frames and routines, such as the distributed control over flows at the UTE level, which belong to a formative context where the institutional separation between task direction and execution is challenged in a deeper way than it actually is, could support the development of the new capabilities. Such capabilities might reveal themselves as strategic, i.e., of benefit to the operations as a whole, although we do not have enough data from the study to reach a firm conclusion on this issue. Finally, the computer-based system could be practically redesigned according to the new formative context: as a platform for simulation exercises and distributed control routines. At the end of our study, a simulation prototype of a segment of the Welding line was built and presented to management as a candidate training tool. The prototype helped to make our point about the need for broadening the skill base of the workforce more concrete.[3] During the follow

[3] Our recent team played the "concreteness game," espousing the prevailing attitudes we discovered in the plant. We built a software object that could be looked at and touched in order to make our conclusions better understood by factory management.

up discussions, the Production manager of the Welding line wondered: *"What is the population of workers, supervisors and managers who would need to be trained on the new tool and be exposed to the principles of systems dynamics?"* The very fact that this issue was raised as a question meant that the old division of labor was not considered taken for granted, especially given the puzzles experienced daily in the plant. It is by asking these kind of questions that management can start inquiring into the existing formative context, and possibly trigger the discovery of a new division of learning, more consistent with the principles and organization of advanced manufacturing.

6. CONCLUSIONS

We can consider the various UTEs as "communities of knowing" (Boland 1995), engaged in learning and problem solving about minor and major breakdowns of production. Our analysis, based on the application of the learning audit methodology has shown that each time a breakdown occurs, the existing formative context triggers interpretive schemes and organizational routines that are driven by the D/A metaphor. In other words, when facing a problematic event, both improvisations and planned interventions are performed by members of the community taking a special perspective, present both in the traditional concept (and technology) of the assembly line and in the new concept of "artisanal, quality work": *building the car bit by bit.* The existing information systems support this kind of "perspective taking." We have also seen that individual and collective learning processes are heavily influenced by such a perspective. Specifically, we have discussed the variety of breakdowns that plague the production process, pointing out those for which the perspective taken by the teams is effective and those for which it is dysfunctional. In the latter situation, the pervasiveness of the D/A metaphor does not lead to a rapid and effective "learning by trial and error." We conclude that UTE members, and the plant management, should engage in "making" operational another perspective, the one of *systems dynamics*, for which the interdependencies among the production events and operations are more visible. Such a perspective can help members construct new understanding and response routines and, most importantly, unleash learning on how to improve the distributed control of operations. Consistent with such a perspective, simulation applications could be made available through the information systems, (a) to be used off-line as a complementary training tool for managers, supervisors, and key members of the UTEs, and (b) to enable the on-line exploration and evaluation of alternative modes of operations.

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