Coordinating Two Knowledge Systems:

A Case Study

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Running Head: Two Knowledge Systems

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This paper explores the ways in which employees in a manufacturing plant understand the relationship between the processes of production and a computer-based inventory and production control system (MRPII). More specifically, this paper examines the conceptual relationships that develop within individuals and how these conceptions are shaped by the activities associated with a given job. Although our study concerns the integration of two specific knowledge systems in adults, it should be understood that the problem of domain sharing knowledge systems is a core problem in the analysis of developmental and educational change. A number of theoretical perspectives and research findings (Piaget, 1963; Vygotsky, 1978; Scribner 1985b; Campbell, Brown & Di Bello, 1991) suggest that the acquisition of knowledge is not a simple "accretion" of new items and "deletion" of old ones. Rather, the learning process seems best described as one in which knowledge comes to be reorganized according to what an individual needs to accomplish.

The data to be discussed were originally collected as part of a larger study concerned with the relative roles of school-based and work-place learning in the acquisition of knowledge required for effective job performance. We conducted cross-sectional and longitudinal studies of employees in two manufacturing plants which had recently introduced a new computer-based inventory and production control system (MRPII) (Scribner, Sachs, Di Bello, & Kindred, 1991).

This paper focuses on workers in four different occupational roles from one of our target plants. Our data were analyzed to examine the way these workers conceptualize the relationship between the processes of production (which are often known in a pragmatic way) and an idealized version of the processes as they are represented in the MRPII system.

The theoretical perspective that best fits the sort of knowledge acquisition that we are studying is activity theory. Briefly stated, activity theory is a contextualist approach to cognition with important differences from other theories of "cognition in context." First, it holds culturally organized human activities as primary contexts for learning and cognition. Second, the theory identifies aspects of activity that have special significance for cognition. These include a) the kinds of tools and representational devices which are employed in an activity (computer systems or blueprints, for example) and which have symbolic as well as instrumental significance; b) the forms of social organization an activity takes; c) the knowledge and skills required for expertise in that activity; and d) the modes of communication which establish a shared knowledge among participants. Third, the theory distinguishes between the social purposes for which activities are organized and the personal motives of those engaging in these activities. Thus, activity theory encourages an integrated approach to research which takes account of interdependencies between two levels of phenomena -- the level of social organization and the level of individual organization.

Activity theory's assumptions about knowledge systems and knowledge acquisition make it especially suited to the present analysis. Five tenets of activity theory address this point.

1. Knowledge acquisition is incidental to many different kinds of activity systems, whether or not they have been intentionally designed for that purpose. That is, merely engaging in an activity in order to accomplish group or individual goals leads to the acquisition of some kind of knowledge of the meaning systems and tools involved. As we have noted elsewhere, "The production of electronic connectors is also the production of people who know about connectors and how to make them" (Scribner et al., 1991).

2. Activity theory assumes that knowledge systems are consensually created through social practices among particular social groups. That is, knowledge systems are not inner mental structures, but a body of ideas, facts and practices existing among social groups or communities. As certain anthropologists (Borofsky, 1991; Geertz, 1973), and philosophers of science (Lektorsky, 1988; Longino, 1990; Popper, 1972) have maintained, conceptual systems are social products and have a social reality.

3. However, an individual's internal model of a given conceptual system is not a simple <u>internalization</u> of a social product. An individual's understanding of a particular domain, and his

or her knowledge of its contents is linked to the kind of activity they engage in. "Although activity theory implicitly holds that human beings construct their knowledge of the world, it points to the importance of differences in the purposes and conditions of activities as a primary source of differences in the way individuals construct knowledge of a given domain" (Scribner et al., 1991).

4. Activity theory further differentiates between two types of knowledge domains in the world. These are "formal" knowledge and "empirical" knowledge. This distinction was initially introduced into psychology by L.S. Vygotsky (1987; for discussion, see Di Bello and Orlich, 1987) and further elaborated by one of his students, V. Davydov (1988). As is shown below, this distinction is vital to our knowledge elicitation techniques and data analysis methods. It allowed us to hold the body of MRPII knowledge as analytically separate from empirical processes of production as we explored how these two knowledge systems are integrated and overlapped within different individuals' talk and within different activities.

5. From the activity theory perspective, domains of activity in relation to a knowledge domain are the things to be identified rather than assumed. A job "title" or domain of knowledge "label" is relatively meaningless unless we can specify the structure of activities that are subsumed under the job title and the concepts of the domain of knowledge that are brought to bear on these activities.

In this paper, we proceed along two different but related paths. On the one hand we employ a detailed analysis of the overlapping knowledge domains, MRPII and production. On the other, we conducted a detailed analysis of what people in four occupational groups are actually responsible for accomplishing, i.e., the goals and activities comprising workers' jobs. These analyses were extremely useful in a number of ways. Our analytic schemes of each knowledge system were developed in previous work and had allowed us to design a comprehensive probe battery which covered the key concepts of MRPII and the key aspects of production (Scribner et al., 1991). These same schemes guided our coding of subjects' talk generated during probe interviews for the present paper. The picture of each person's understanding rendered by this latter analyses could be compared to the scheme of each person's day to day activity, allowing a sensitive analysis of the relationship between individual activity and individual understanding of a shared knowledge system.

Because the use of analytic knowledge schemes and activity schemes is a novel approach to research in skills acquisition, each is further discussed in more detail below.

Analysis of the Knowledge Domains

Our analysis of the domains of knowledge is motivated by the fourth tenet above, i.e., Vygotsky's (1987) distinction between theoretical knowledge domains and empirical knowledge domains, which was later substantially refined by Davydov. Vygotsky distinguished between conceptual systems developed and acquired in the course of everyday life ("spontaneous" concepts) and systems which are elaborated in various intellectual disciplines ("scientific" concepts). He argued that these two types of systems not only have different properties but have different courses of acquisition. Davydov and his colleagues substantially refined Vygotsky's dichotomous scheme, replacing it with one more firmly grounded in epistemology and psychology (Davydov, 1984). In particular Davydov recognized the importance of core organizing concepts as unique to formal domains of knowledge. In addition, he showed that in depth understanding of a given knowledge domain is evidenced by mastery of its core concepts and their relations (See Hedegaard & Chaiklin, 1990; also see Kozulin, 1990, for a brief and lucid description.) Researchers interested in the pedagogical value of this notion have developed methods of teaching science to children employing schemes representing the relevant core concepts of the target domain (Rubtsov, 1991; Hedegaard, 1988).

The present research adapts Davydov's contrast pair and his emphasis on core concepts to adult cognition and learning. We characterize a knowledge domain as formal if it is founded on theoretical concepts and their relationships. Empirical knowledge domains are organized around notions and things encountered experientially. The notion of expertise that is part of this formulation is more than mere "competence"; the individual who has become expert in the application of a formal domain to real world problems can be characterized as having a flexible mental model that allows her to extemporize when faced with novel tasks or non-routine problems. This is very different from an individual who has considerable know-how, or various procedures and a history of numerous tasks and problems that go with them. For Davydov, possessing a firm understanding of the core underlying conceptual relations allows this kind of implicit flexibility. Other literature dealing with specifically with the development of expertise has identified this kind of expert profile under other terms (e.g., Polanyi, 1986; Dreyfus & Dreyfus, 1986; Feldman, 1988; and Chi, Glaser, & Rees, 1982).

In this study, we have viewed MRPII as a formal model of empirical production processes. In contrast, we have viewed production as an empirical domain or "craft" involving real processes in real time and space. Moreover, exactly because production is not a formal *theoretical system*, production concepts do not exhibit the same systematic structures as MRPII concepts.

In conducting our larger study (Scribner et al., 1991), it was necessary to develop original and domain specific knowledge elicitation instruments in order to tap workers' knowledge of MRPII and production. Two extensive preliminary analyses informed our knowledge elicitation questions and tasks. First we conducted an analysis of texts and technical materials in order to isolate the core organizing concepts and underlying theoretical assumptions implicit in MRP's algorithms and conceptual objects (e.g., Orlicky, 1975; Fogarty, Blackstone & Hoffman, 1991; Vollman, Berry & Whybark, 1988; APICS MRP Planning Committee of the Curricula and Certification Council, 1986). Second, we conducted a comparable analysis on the key aspects of production. For this task we turned to ethnographic data from our primary fieldsite on the processes of production and manufacturing texts (Timms & Pohlen, 1970).

Once we had identified the core concepts and essential aspects of the respective systems, we were able to develop comprehensive conceptual schemes of each knowledge system that represented a collective model of what could be known. From these we were able to generate a probe battery which included questions and quasi-experimental tasks covering the concepts of both systems. These batteries were tested for comprehensiveness on actual MRPII and production experts. In the current study, we used these same schemes to inform our data analysis methods.

An analysis of MRPII's conceptual structure was especially valuable; besides providing a basis for designing knowledge elicitation tasks, this scheme was important for developing a data analysis method that could examine both breadth and depth of MRPII knowledge. (The analytic method used for developing this scheme of core and peripheral concepts is detailed elsewhere; Scribner et al., 1991; and Di Bello, forthcoming). This allowed us to distinguish between behavior and speech pertaining to the core concepts and to the more peripheral aspects of MRPII.

A Brief Description of MRPII and Production

MRPII stands for a family of computer-based systems that integrates information from all aspects of a company's operations and uses it to make decisions (recommendations) regulating production and inventory.

MRPII has been characterized as a theory of manufacturing. It instantiates certain key economic concepts such as zero inventory and just-in-time production and is based on principles of manufacturing (for example, formulas regulating how future orders are forecast) developed over the last several decades (Harrington, 1974; Hendrick & Moore, 1985; Timms & Pohlen, 1970). Its objects and procedures are generically defined and the system is content-free until implemented in a particular plant. Its power as a predictor is contingent upon the data used (the content upon which the logic operates) and the extent to which its assumptions match the way things are actually made in a given setting.

Employees working with the system must translate the company's anticipated demand into a form that the MRPII system can understand. This is done via a Master Production Schedule (MPS) which the system then interprets as a set of long range, abstract production goals for the company's finished goods. With the information the system has on "what" a particular finished good is (e.g., what parts go into it, what operations are involved, how long it takes to make each of its component parts and assemble finally it) it makes recommendations for every action leading up to the company's pre-set goals. This includes deciding upon start-dates and quantities for production orders and determining the most efficient sequence of production events. Employees using the system must evaluate these recommendations for their feasibility and alter them slightly (or drastically) on a continuous basis to fit real-world constraints. For example, the MRPII system assumes an ideal world with no shipping delays, labor shortages or the advantages of bulk purchasing of raw materials.

The type and level of employees designated to fulfill various decision making and data input roles vary greatly from plant to plant. In general, evaluating the system's recommendations properly requires considerable understanding of MRPII logic. The responsibility for doing this usually falls to either management personnel or those who have been specially trained in MRPII. The difficulty in learning MRPII principles is shown in that MRPII installation often fails or the system ends up being relegated to the role of inventory database when (for whatever reason) employees cannot make use of its higher functions. In this case, its implementation is not considered successful by industry standards. As indicated in our previous work, "success" in industry terms is highly dependent upon how well workers understand the system and its way of representing the products of their plant (Scribner et al., 1991).

As indicated, MRPII is an idealized model of the flow of material. In Davydov's sense, it is a <u>theory</u> with a set of internally cohesive principles. Our analysis revealed that the representational form of the data and the system logic are based on three core organizing MRPII concepts from which all elements of the system inherit their structure and relational rules. These are shown in Figure 1.

Insert Figure 1 here

Jobs Classified According to Leading Activity

A major idea to be explored here is that the formal and pragmatic systems will interrelate differently, depending directly upon the job domain in which they intersect. Therefore, it was necessary to render an analysis of our target jobs and classify them according to "leading activities." We used extensive ethnographic data from our field site and in depth work history interviews to identify the primary goals and responsibilities that organize the activities associated with each job (see Appendix 1 for details of individuals' job descriptions and Scribner et al., 1991).

We found further that job activities are distinguished by two specific qualities: 1) The degree to which the goals of the activity compel the employee to "construct" procedures, tools, or reports; 2) the degree to which the activity requires the worker to execute standardized or routinized procedures as a goal in itself. Does the job related activity require a worker to execute practices or interpret and act upon information from both systems? We isolated four categories of leading activity that span our target jobs, involve both knowledge systems, and have both procedural and constructive forms. These four categories are scheduling, trouble shooting, information handling and supervision of others. An inexhaustive list of worker activities per our analytic scheme is shown in Table 1.

Insert Table 1 here

Method

Subjects

All data reported here came from the 14 subjects who worked at Kemps Electronics. In addition to data from probe interviews, extensive observational and work history information was collected from these individuals; we observed employees on the job and conducted in depth work history interviews. This information was necessary when interpreting each individual's talk, especially when it turned to the specifics of her job or day to day responsibilities.

Kemps Electronics is a family-owned manufacturing plant in New York employing approximately 500 people. It produces radio-frequency connectors used in devices such as video panels, oscilloscopes, televisions, computers and submarine equipment. The small size and great variety of these connectors (Kemps produces 7,000-8,000 finished goods requiring 20,000 component parts) means that the company has a significant inventory to manage. Kemps implemented MRPII seven years ago.

The subjects each belong to one of four job groups (Managers of Material Control, Planners, Expediters and Production Supervisors). After an extensive analysis of the activities involved in various jobs, we chose these four occupational categories because all involve both the MRPII system and knowledge about processes of production, but in markedly different ways.

Procedure

The findings reported here result from analyses of data collected during semi-structured probe interviews which included questions and quasi-experimental tasks. As indicated above, this battery of 27 probes is a knowledge elicitation device developed to assess workers' knowledge of MRPII systems and manufacturing processes [see Scribner et al., 1991 for greater detail on this battery].

Four probes (of the original 27) were designed to examine subjects' conceptual knowledge of the relationship between MRPII and production, if there was such conceptual knowledge; i.e., these questions and tasks addressed the relationship between MRPII and production, but could be adequately approached in a purely MRPII or purely production way. In this way we could see if subjects were thinking about and comparing the two systems when given free reign to do so or not. These were Probes 1, 7, 8 and 14 (see Appendix 2) of the original battery of 27. This paper concerns analyses of verbal data from these probes and task performance from Probe 7.

Probe 1 required the subject to examine an actual part made at Kemps and describe how it is made. Similarly, Probe 8 required subjects to describe a manufacturing sequence, but one that was typical of all kinds of finished goods. These were deliberately open ended questions designed to encourage the subject to produce a linear sequence which made the most sense to her. Subjects could begin this sequence with an MRPII or production based starting point and continue the sequence from the point of view of an MRPII system, shop floor events, or an interplay of both. For example, a subject might say that the first event is a customer order entered into MRP, while another subject might discuss the object's fabrication from raw material to finished good on the shop floor.

Probe 7 was a card sorting task that generated two kinds of data: (1) subject's card arrangements and (2) the subject's talk while sorting. They were analyzed separately because many times they had little to do with each other. For example, a subject might talk about alternative sorting options that were not carried out, or produce a sort according to specific principles and yet not discuss those principles. Each card had information corresponding to the actual parts manufactured at Kemps including the name and part number of a component or raw material and information regarding its relative level in an MRPII hierarchy. The cards as a set comprised one end item, all of its components and all of the raw materials for those components manufactured in-house. Processing information is contained in part numbers. For example, the code "M07" in part TT-777-6 M07 indicates that this component is silver plated. The kinds of information on the cards afforded various sorting options. These included sorting according to a linear processing sequence, a production-based part grouping and an MRPII end-item hierarchy (see Figure 2 for illustrations of these options). After producing one sort, each subject was encouraged to produce an equally reasonable alternative.

Insert Figure 2 here

Probe 14 required subjects to explicitly compare MRPII and production and discuss any discrepancies between them. The subject was then asked to evaluate the notion that an MRPII system could actually run a manufacturing plant if all the information about production events entered into it were accurate.

Coding Methods

Our first aim was to quantify subjects' discourse and compare relative proportions of MRPII talk and production talk among individuals and across jobs. In order to locate MRPII and production concepts in our subjects' probe responses, we needed a unit of analysis for classifying discourse as characteristic of MRPII or production. Using our original analytic scheme of MRPII's formal rules and concepts, we were able to generate a list of MRPII terms and rules for their appropriate use. Using our scheme of production concepts, we generated a comparable list of production terms and relations used by workers to talk about manufacturing and production and that are common parlance in manufacturing environments. Some MRPII terms had production counterparts, and some terms were unique to each system. For example, "end item" is an MRPII term for the equivalent production term "finished good," while "rework" is exclusive to production, and "BOM explosion" is unique to MRPII.

Comparing instances of talk classified as MRPII with those classified as production showed that MRPII and production talk are notably different, particularly in conventional terms. In general, MRPII talk is generic and technical, while production talk is concrete and context-specific. Thus, units of talk can be coded as characteristic of MRPII or production in the context of probe responses. Hence, we needed a method for establishing uniform units of talk from the transcripts and analyzing the patterns of shifts in talk between MRPII and production. We turned to the literature on discourse analysis, semiotics and code-switching in order to inform our method and provide effective strategies for capturing different systems of knowledge in discourse.

Stubbs' (1983) discourse analysis affords some insight into the nature of system-shifting in our data. Stubbs argues that speakers appropriate a wide range of styles and jargons to express their knowledge systems, and this often entails shifting. Relevant literature on code-switching (Sanchez, 1983; Poplack, 1980) attempts to articulate systematic patterns that predict where a language switch can or cannot occur in relation to the social context and the proficiency of the speaker. We devised methods based on code-switching models in order to map the switches between MRPII and production in our speech data.

We modified Gee's (1986) method for marking the talk into codable units. Gee has devised a scheme for handling narratives in terms of primary and compound units. The primary unit is the "line," or phrase. Lines build "stanzas," and finally, stanzas make up "topic units." Gee's work inspired our method, as the units are conducive to both quantitative and qualitative analyses. We divided the transcribed speech of each subject into minimal subject/predicate units. We called these units "propositions," which we coded according to the following rules.

In the transcribed responses, propositions were segmented at the minimal subject-predicate phrase unless:

1) the predicate consisted of only one verb that required the subsequent proposition for meaning (e.g., "everybody **thinks** they've got 2000 pieces /..." as opposed to "they **crimp / before they assemble** / ";
2) the proposition was cut off by the interviewer;
3) the interviewee uttered a one-word response.

All false starts, stuttering and the like were included in the logically closest segment whenever possible; however, repetitions were counted as separate propositions. Propositions then received one of four possible codes:

1) MRP, where any talk of the computer system and its physical, functional and theoretical aspects were discussed;

2) Production, where the transformation of parts, resources and utilization of material and quality control were discussed;

3) Non-applicable (NA), where talk was either clarificational, self-reflective, repetitious or generally irrelevant;

4) Indeterminate (IND), where the proposition was cut off or impossible to understand from the audio-cassette.

Since sequential propositions could have the same topic, object or context, we regarded these strings of related propositions as "streams." A string of continuous propositions was identified as a united stream if:

1) propositions addressing the same knowledge system were uninterrupted. For example, Ronny's last four production propositions (as in Table 2) composed one production stream.

2) sequences interrupted by no more than one consecutive NA or IND proposition were counted as one stream. For instance, the first six propositions in Helen's excerpt (Table 2) compose a production stream. However, the length would be four propositions.

New streams were counted if:

1) the interviewee switched from one system to the other;

2) *the sequence of propositions within the same system was interrupted by more than one consecutive NA or IND proposition.*

Insert Table 2 here

Examining Subjects' Talk for Switches

Previous work in psychology and linguistics has shown that code switching can be an indicator of flexibility with two languages or two knowledge domains (Poplack, 1980). Furthermore, Poplack suggests that "intra-sentential" code-switching (where a speaker uses two languages within a proposition) indicates that a bilingual is equally proficient in both of those languages. Therefore, the protocol data were examined for patterns of MRP/production switches among the coded propositions and streams. These switches were defined as instances when the subject *spontaneously shifted her talk from MRPII language to production language or vice versa.*

The number of such switches were counted and compared to the total number of streams, and proportions were calculated. Each stream ending constituted an opportunity for a topic switch. Therefore, proportions were calculated as:

$$\frac{\text{Number of MRP/Production Switches}}{\text{Total Number of Opportunities to Switch}}$$

For example, a response containing a sequence of four production streams followed by one MRPII stream contained one MRP/production shift within five streams. The proportion of switching would be 20 percent. Finally, if there were switches within propositions or very frequent switches between individual propositions, there was evidence for a high degree of balance between the two systems, which was handled in greater detail by the following analysis of coordinated talk.

Examining Subjects' Talk for Coordinated Knowledge

Two of our probes, 7 and 14, explicitly provided opportunities for subjects to compare and contrast the two systems. Therefore, protocols for these probes were subjected to a second coding scheme. We coded transcripts of talk from these probes for evidence of "coordinated talk," i.e., talk with the larger purpose of discussing how MRPII and production are related.

The same protocols that had been divided into numbered propositional units were used and coded for streams of propositions that had one or more of the following characteristics:

1. attempts to compare the two systems at the core concept level.
2. attempts to explain a relationship between specific aspects (operations, structures, concepts) of one system with related aspects of the other. Specific aspects could be either functional or conceptual.
3. attempts to represent the "perspective" of one system upon the other.

Regarding 2, we worked out definitions of functional and conceptual talk and coded these streams accordingly. Functional talk concerned discussions of the day to day operations of production and MRP, and the ways various aspects of these operations are related. For example, functional talk might address how new data about what has happened on the shop floor is entered into the MRPII system continuously throughout the day, but is not actually incorporated into the system until an overnight "regeneration" takes place.

Conceptual talk involved the goals, logic, methods of representation and assumptions implicit in each system. All conceptual talk was coded as either core conceptual or local conceptual. Core conceptual talk addressed the relationships between key organizing principles of MRPII and key goals or principles of production. Local conceptual talk addressed more particular aspects of each system or a partial relationship. Necessarily, these streams included propositions and whole streams that had been previously coded as either MRPII or production.

The streams of coordinated talk were then quantified in the same manner described for MRPII and production streams, and proportions of coordinated talk were calculated in relation to an individual's total codable talk.

Subjects' Card Sorts on Probe 7

As indicated above, Probe 7 required subjects to sort cards representing components of a particular end item. Each subject was asked to produce two alternative sorts. Subjects were encouraged to describe and explain their sorting choices as they made them. The resulting card arrays were recorded graphically and analyzed for the logic guiding the sorts. When the guiding logic was not clear from the actual sort, we examined the verbal protocols generated while sorting for clarification.

A sort was defined as consisting of an entry point in the talk, i.e., what kind of information a subject addressed in first viewing the cards, (e.g., part, process or item level); a card arrangement (which could be an adjustment to a sort already arranged by the subject or a unique sort); and a dominant organizing scheme or leading activity. Each sort was analyzed to determine these aspects.

We classified card sort arrangements as MRPII or production driven. MRPII sorts were those which conformed to an item hierarchy according to the three relative levels designated on the cards. Production sorts were those that described a linear sequence of operations and assemblies or were organized according to production-based categories, such as whether the components are manufactured in house or purchased from a vendor.

Results

Results of MRP/Production Talk Distribution

All 14 subjects' protocols contained both MRPII and production talk. Each subject produced streams of various sizes within each knowledge system. Table 3 displays all 14 subjects, their jobs, and the proportions of MRPII and production talk observed in their combined responses to all four probes.

Insert Table 3 here

As is clear in Table 3, job category is strongly related to relative proportions of MRPII and production talk overall. Material Control Managers as a group showed equal proportions of talk in each domain. Other workers tended to show distributions closer to 70/30, in one direction or another. A comparison of these distributions with each worker's individual work history showed that each tended to talk within the domain with which she had the most day to day contact, training, work history or a combination of all three.

For example, a closer look at three individual subjects (see Table 4) illustrates the disparity in distribution of MRPII and production talk among subjects with different jobs and different educational backgrounds.

Insert Table 4 here

Of these three in Table 4, Fred's talk is most evenly distributed across both systems. His position as Manager of Planning and Production Control, requires him to focus on how MRPII predictions and production events influence one another. Therefore, he is called upon to think equally about the two systems towards this goal. In addition, his work history shows that he has held supervisory positions in both material control and production in the past fifteen years.

In contrast, Ben is relatively inexperienced with production, having spent 6 out of 8 years in manufacturing as a Planner. However, he is highly educated in the formal aspects of MRPII systems; i.e., prior to this probe interview, he had earned APICS certification as an MRPII expert through course work and self study outside the work setting. The largest proportion of his talk is in MRPII terms. Helen, a Production Supervisor, has an eleven year work history in production, works minimally with MRP, and has no formal MRPII training. Specifically, she oversees and expedites manufacturing orders in all stages of production on the shop floor. Before becoming a Production Supervisor, she was an Expediter in the machine shop and an Expediter in the assembly area.

Switching

The analysis of patterns of switching in talk from MRPII to production (or production to MRP) revealed interesting differences in spontaneous switches. The average proportion of switches for the group as a whole was 57%. Material Control Managers averaged a higher 74%, Planners, 54%, Expediters, 67%, and Production Managers a low 41%. However, the low score for Production Managers is due largely to one subject, Warren, who did not produce enough talk to code comparably for switches.

Table 5 displays each subject's MRP/production distribution and his proportion of spontaneous switches. This table shows a very high relationship between relative proportions of MRPII and production talk and proportion of spontaneous switches. Those who made frequent switches (above 70%) in their language generated close to equal amounts of talk in each domain. Such a correlation between distribution and proportion of switching is interesting given that it would be possible to switch domains frequently and yet have very skewed distributions, or have perfectly even distributions with as few as one switch. The high relationship between frequent switching and even distributions suggests that equal facility in both domains may promote rapid and frequent switching in the type of language used. This correlation may also suggest that individuals who are using language from each system equally and making rapid switches view these two knowledge systems as inextricably linked when called upon to answer questions about manufacturing. The high proportion of spontaneous switching may thus be driven not only by competence in each system, but even more by the way the subject is thinking about how MRPII and production are related.

Insert Table 5 here

Coordinated Talk Analysis

All 14 Kemps subjects answered Probes 7 and 14. Of these, seven subjects produced coordinated talk on Probe 7, and nine produced coordinated talk on Probe 14. Table 6 shows all results from this analysis and indicates those who produced coordinated talk of any kind on these two questions.

Insert Table 6 here

On Probe 7, the group averaged 28% coordinated talk, with a range of 8% to 71%. This range shows considerable variability at first glance, but is attributable to two outliers; the second highest percentage was 33% and the second lowest 15%. There were no significant differences by occupation in the quantity of coordinated talk. However, as Table 6 indicates, there were interesting trends by occupation for the instance of coordinated talk. Specifically, Material Control Managers produced a high degree of coordinated talk without exception. Planners and

Production Supervisors tended not to produce coordinated statements, with some exceptions in each group.

On Probe 14, nine subjects produced coordinated talk. Subjects averaged a slightly higher 31%, with a much tighter range of 20% to 42%. As with Probe 7, there were no significant differences by occupation in the quantity of coordinated talk, and there were similar trends for the instance of coordinated talk by occupation.

Table 6 also indicates the type of coordinated talk produced. These types were found to be embedded. In other words, all subjects who produced any coordinated streams produced functional streams. Some produced conceptual streams in addition, and three subjects (Fred, Sam and Joe) produced conceptual streams that touched upon core conceptual aspects of the relationship between MRPII and production in addition to local conceptual and functional streams. The tiered nature of these types of coordinated talk suggests a developmental sequence with functional comparisons between MRPII and production occurring first, local conceptual next, and comparisons at the core concept level occurring later, if at all.

Results on Card Sorting Task

Card sort arrangements broadly differed as either MRPII or production driven. These results are shown on Table 8, column 4. In order to further differentiate the production sorts, which were highly various, we examined them for differences in strategy and organization (see Table 7). Three kinds of production sorting schemes emerged: (1) empirical description of a linear sequence of operations involved in the production of a finished good, (2) categorization of parts based on processing stages, specifically the distinction between parts used in actual assembly and parts packed loosely with the end item ("assembly parts" and "packing parts"), and (3) categorization of components that distinguish whether the parts are made in house or purchased from a vendor ("make" and "buy" parts).

Insert Table 7 here

Table 7 displays each individual's sorting strategies. Four individuals produced MRPII item sorts. They were Ben, Manuel, Fred and Sam. Three of these subjects also produced a production alternative; Fred's production sort was an assembly sequence, while Manuel's and Sam's were make/buy sorts. Ben was the only one of all fourteen subjects to produce only an MRPII arrangement of the cards. All remaining individuals produced only production sorts. Four produced production sorts based on make/buy part categories (Manuel, Raymond, Sam and Ronny). Seven produced production sorts based on assembly/packing part categories. Only Ronny produced two distinct category based sorts, a make/buy sort and an assembly/packing sort. All other production sorts were based on operational sequences. Nine produced two distinct kinds of production sorts, and the two Expediters produced two versions of a single kind (linear processing sequences).

Particularly interesting results occurred within the group of Planners indicating that responses to Probe 7 are highly related to the actual activities (and even specific procedures) of Planners' jobs. All Planners (except Ben) produced one category-based production sort as one of their two sorts. Of these, the three End Item Planners (Genevieve, Fay and Jerry) each produced one assembly/packing sort. In contrast, the two Component Planners (Manuel and Raymond) each produced a make/buy arrangement. These results map directly on to major categories of activity that differentiate end item planning from component planning.

Through our extensive ethnographic observations of Planners doing their jobs, we have found that the actual job activities of Component Planners differ in structural organization and content from that of End Item Planners. Component planning consists primarily of two sets of work activity, purchase part planning and make part planning. These parallel activity sets entail different tools, consist of different actions, and are carried out separately from each other. End Item Planners, on the other hand, plan all end items using a procedure similar to make-part component planning, using a single set of tools and activities (see Scribner et al., 1991).

The job of component planning is structured by the distinction between make and buy parts, and these categories led Component Planners in their sorts for Probe 7. Where make/buy was the leading organizational scheme for Component Planners' production sorts, End Item Planners did not even mention these categories, with no exception.

In the planning and releasing of end item orders, on the other hand, Planners must know which components are needed at different points in time in the production of an end item. In particular they need to know which components are not needed until the packing stage at the end of the part's production, in order not to delay the release of an end item order unnecessarily. For Component Planners, this is not an issue. Accordingly, End Item Planners created production sorts based on the distinction between parts used in the assembly process and packing parts, while no Component Planners mentioned this distinction.

* * * *

Taken separately, these results suggest that individuals are influenced by their job activities in the way they think about MRPII and production and the relationship between them. When these results are placed next to each other, by person and occupation, and compared with previous results (reported in Scribner et al., 1991), the profiles that emerge strongly support the notion that an individual's activities on the job shape her thinking about MRPII and production and the way she conceptualizes the relationship between them. Table 8 shows the four types of results reported above for each subject and includes each individual's educational background and years of experience in manufacturing.

Insert Table 8 here

A particularly interesting profile is shared by Fred, Sam, Ronny and Joe. All had even distributions of MRPII and production talk (column 1), had very high proportions of spontaneous switching (column 2) and showed a multi-layered way of talking about the relationship between MRPII and production (column 3). Fred and Sam also produced both an MRPII and a production based card sort, demonstrating flexibility between the two systems. Ronny and Joe showed flexibility within production, creating two distinct types of production sorts. These profiles are consistent with our notion of an expert's understanding (and are supported by our data on their work performance).

We looked to work and training histories to see what might be responsible for their coordinated approach to these probes. In addition, we compared the results in Table 8 to how workers fit into the activity scheme shown in Table 1. The way that each worker's activity fits into our analytic activity scheme is shown in Table 9.

Insert Table 9 here

Their work histories and MRPII training backgrounds only partly explain this profile; each of these four individuals had a long history in manufacturing <u>or</u> extensive MRPII training, but no one had both, suggesting that certain kinds of work experience - particularly constructive activities - may be functionally equivalent to classroom training.

When comparing their profiles in Table 8 to their activity in Table 9, it is clear that the constructive nature of their job activities plays a strong role in their highly coordinated probe performance. These four individuals, all Managers of Material Control or Production, must make the systems work together as a primary *responsibility of their jobs. These responsibilities lead them* to engage in constructive activities that involve coordinating key aspects of the MRPII system and fundamental production issues. In other words, they use information from each system to make decisions and formulate plans for both systems. This is very different from usual end-user use of a computer system, which involves implementing or using plans developed by others. For example, Material Control Managers are required to construct and revise MRPII Master plans; such plans require considering production constraints and MRPII goals simultaneously in a broad and far reaching sense and must be constantly modified as plant priorities or conditions change. In addition, once entered into the MRPII system, these plans provide the data used to generate its recommendations. Furthermore, all four individuals must evaluate reports on plant performance, interpret MRPII generated reports and shop floor progress reports, and make decisions or effect actions that will produce desired performance results. These types of activities compel workers to *focus on the discrepancies and deep structural differences between the two systems in their* attempts to construct plans and make decisions that address both systems effectively. For example,

> Fred on Probe 7:
>
> ... We eliminated the subassembly. That was another level that was set up to add more lead time, so we eliminated it... Physically it exists, we have to manufacture a subassembly for each connector but in the structure that we have set up in MAPICS it doesn't exist. It exists on the floor. There's a lot of things that exist on the floor that you can't possibly put into bills and or the routings that we're writing up.

Fred on Probe 14:

> The system is only able to gather specific types of information ... It can't inspect a part. It can't tell you how to repair something if it's defective. Things like that.

In contrast to these four subjects, those holding other kinds of jobs are not *required to* actively and routinely focus on the inherent discrepancies between MRPII and production in other than "functional" ways. Rather, as Table 9 shows, their responsibilities involve implementing schedules and decisions made by others, and identifying relatively local conflicts between MRPII and production. The resulting differences in activity turn out to have important consequences. Overall, their profiles in Table 7 reflect this; while their talk shows that they think about both bodies of knowledge, they produce relatively little coordinated talk and a significantly lower proportion of switching within protocols. *These profiles indicate that these subjects are thinking about* production and MRPII alternately and that they focus predominately in one domain. However, there were still interesting individual differences despite an overall similarity. The further differences between these subjects on various measures are due largely to 1) the specifics of each person's job responsibilities, 2) the length of time working in manufacturing, and 3) the type of MRPII education received.

Planners

Planners at Kemps do not routinely engage in activities that address the fundamental differences between MRPII and production. They spend most of their time reviewing MRP's recommendations for order releases. The plans that drive these recommendations are not routinely examined by Planners even though they are available for review. Rather, Planners work mainly with very specific information from both systems and rarely have to resolve problems that may arise when global MRPII predictions do not map smoothly on to production events. As indicated above, such problems are generally identified and handled by the Material Control Supervisors.

Planners in general dedicated about 70% of their talk to production, showed low proportions of spontaneous switching, produced little talk coordinating MRPII and production, and did not produce MRPII card sorts on Probe 7. The only exception to the general Planner profile was Ben, whose distribution in column 1 of Table 7 was a mirror image of the others'. He is the only Planner to produce an MRPII item hierarchy as his first and only sort on Probe 7. It is difficult to say from these data to what degree Ben's differences were attributable to his extensive MRPII knowledge or to his ignorance of the meaning of other information on the cards. Most Planners recognized the part numbers and process codes quickly, and seemed to have been led by this information to produce sorts based on their knowledge of how these objects are actually made. This tendency was even greater among Planners who had never worked at a plant other than Kemps (Genevieve, Fay and Jerry). To Ben, who had worked at Kemps for less than a year and had not begun his career in production processing, most of this information was meaningless. He comments on his own performance:

> Ben on Probe 7:
>
> I happen to know the KC part number is the end item ... but if I didn't know the part numbers, it says relative level one, so that would be there [he places it and the other cards to represent an MRPII hierarchy] . . . I don't know if I would know what items go together [during the production process]. If you were to put the actual parts here in front of me, I don't think I could put the connector together.

On question 14, which specifically asks the subject to compare MRPII and production, Ben's performance was typical of all Planners. Planners in general produced little talk that coordinated the two systems, and when they did, the talk focused on functional relationships. Ben's talk in response to Probe 14 shows that expertise in MRPII is not sufficient to understanding its relationship to actual production. He produces no talk that can be coded as an attempt to explain or describe the relationship between the two systems.

Planners' relatively low average for switching supports the notion that planning activities do not require workers to consider MRPII and production simultaneously. The two notable exceptions are Manuel and Genevieve, who show high switching frequencies as well as slightly higher proportions of MRPII talk in their protocols. Their differences from the other Planners may well be attributable to the fact that they have considerably longer experience in manufacturing than any of the other Planners (Table 8, column 6), including many years of pre-MRPII experience. Perhaps this previous knowledge, richer in production content, has provided a contrasting scheme as they think about MRPII and its relationship to production. In other words, for these two, the differences and similarities between MRPII and production may be more striking; both produced a number of descriptions of the functional relationships between MRPII and production in response to Probe 14. This is interesting considering that three of the other Planners produced no coordinated streams for this probe, and Fay produced only one concerning a common data entry time lag. (Data about production events entered into the MRPII system are not incorporated into the system's plans until the following day).

> Genevieve on Probe 14:
>
> MAPICS is telling you to release an order this week, but you can't because you don't have the parts so you have to wait till next week.

Manuel on Probe 14:

> There's always something that happens. You lose the parts and MAPICS is saying they issued those parts to that work order. Meanwhile, they can't find it so we'd have to cut a new order, or if we have parts in stock, we have to reissue to the same M O.

The most interesting differences between Planners were exhibited in their card sorting behavior on Probe 7, as detailed above (see also Table 6). More than any other measure, card sorting behavior reflected specifics of each Planner's activities with the kinds of items they handle. This is an expected result because Probe 7 required subjects to exhibit their thinking about the relation between a finished good and its components, which is a major part of a Planner's activity.

<u>Expediters</u>

The two Expediters showed a relatively high proportion of switching, and Harriet showed an almost even distribution of talk between MRPII and production. Both produced coordinated talk on Probes 7 and 14. On the card sorting task, both Harriet and Juan produced two production sequence sorts with some MRPII features (e.g., Harriet seemed aware of MRPII levels as they relate to processing sequence, but did not produce an MRPII hierarchy). Clearly the Expediters are thinking about MRPII and production as related and are able to discuss relationships between MRPII and production. However, their talk reveals that they do so in a highly specific, concrete and functional manner.

Harriet on Probe 14:

A job was stamped. And the stamping operation didn't get entered into the system. Then we can't tell if it was really stamped. We assume that operation wasn't done. So usually, it's always best to work both systems. The floor and the computer. You should do a double check.

Given their job responsibilities, the concrete nature of their talk is not surprising. Although they work with information from both MRPII and the shop floor to expedite customer and manufacturing orders and troubleshoot problems with outstanding orders, they do so on an order-by-order basis. Therefore, although their responsibilities compel them to consider the relationship between MRPII and production to the same degree, perhaps, as Material Control Managers, these duties do not involve identifying or resolving systemic problems.

Production Supervisors

Unlike Joe, who is the Manager of Assembly, both Helen and Warren hold supervisory jobs that encourage them to focus primarily on production. Specifically, Helen, as Supervisor of Manufacturing and Customer Service, expedites orders using minimal information from MRPII and is in constant contact with numerous personnel from the shop floor. In fact, her job requires her to literally tour the shop floor most of the day. Warren supervises stockroom personnel. Although he sees MRPII reports having to do with inventory, he is mainly involved with actual part counts (physical inventory), weighing and storage of stock, and the daily issue of parts needed for order. The heavy involvement with production and shop floor activities has clearly influenced their thinking. As Table 8 shows, their profiles are heavily production-oriented. Both have a heavy proportion of their talk in production, relatively low proportions of switching and no talk indicating the coordination of MRPII and production. Further, neither produces a sorting result on Probe 7 that conforms to MRPII principles (Table 7), and they each produced two production based card sorts.

> Helen on Probe 14:
>
> Sometimes if I'm following a connector, I know exactly how many are made. Then if I look in a tube and see something wrong, then I go back and I make them make a stock check because I've been following it.

Summary

All of our subjects generated both MRPII and production terms in response to our probes. However, an analysis of the content of talk itself revealed that informants focus on very different aspects of each system and on very different aspects of the relationship between MRPII and production. These differences seem to be related to a number of factors, but mainly to the goals of the job itself. Workers come to understand the same systems in different ways, according to what they must accomplish while working.

Additionally, there was great variation between informants in their ability to "move" between systems discursively. Subjects with the greatest ability to "move" between systems in their talk tended to have greater conceptual grasp of each system and its multi-layered relationship to the other.

The individual differences were not related to formal education or years on the job as much as to occupation or, more specifically, activities engaged in as part of doing one's job. This seems especially true of the way the two systems are coordinated.

Within an activity theory framework, occupations can be characterized as *activity systems.* The ways each individual encounters the MRPII system, and the consequent meanings derived, depend greatly on his or her job responsibilities and goals. Such goal organized encounters, which are related to the larger purpose of getting a job done, have an impact on learning that is more predictable and more marked than other kinds of training or number of years of experience.

We identified two qualitative kinds of activities that workers engage in for the purpose of performing their jobs. The first type is "constructive", where the worker is required to use information from both systems in order to construct schedules, data or recommendations in such a form that they can be used by both systems to fulfill a goal that has no set procedure. These constructive activities were needed to accomplish both global or far-reaching goals (e.g., planning the purchase of raw material for a year) and more "local" ones (e.g., investigating a lost manufacturing order). The essence of such activities is that they require the workers to use the tools of each system in an improvisational way in order to fulfill specific goals. The second kind of activity is "procedural", where the worker is required to execute routine procedures, as a goal in itself. Table 9 shows our notion of the cognitive implications of these types of goals.

The extent to which a worker had an in depth understanding of MRPII and its relationship to production varied considerably with the degree to which "constructive" activities were needed to fulfill the goals of her job.

It seems from our data that the goals, and subsequent actions required to accomplish them, may create incidental learning opportunities that explain the disparity in the kind and depth of knowledge workers had about MRPII and its relationship to production

Conclusion

This study has made two readily identifiable contributions. Besides establishing a clear relationship between activity and mental models, we have developed and refined novel methods of knowledge elicitation and speech data analysis. In addition, by using activity theory as a useful frame of reference, we have also contributed to its refinement and particularly its useful application to adult learning. However, there are other implications from this research. These concern the general problem of expertise and the analysis of knowledge systems, as well as the distribution of responsibilities in a work setting. After a discussion of the first three points above, we will return to some of the directions suggested by this work.

The results reported above demonstrate a clear relationship between work activity and an individual's understanding of two knowledge systems and their relationship to each other. We have shown that there are cognitive consequences to not only what a person does, but also to the nature of engagement. That is, when workers are engaged in formulating the actions that will accomplish a goal, they gain a deeper understanding of the knowledge systems involved, and this is particularly striking when they are responsible for constructing artifacts (such as reports, training materials, or schedules) that use information from both systems in order to inform further action that in turn affects each system. According to Davydov (1988), an individual must construct a formal knowledge system for herself mentally before truly understanding it. It seems clear from these results that the workers develop the deepest understanding of the parts of the system that they must engage with in this way; for example, in order to make a master schedule an employee must begin by asking herself how the MRPII system thinks about time and items and how its viewpoint is different from a more everyday notion of time (linear, sequential) and item. Therefore, it is not the act of constructing schedules, reports, or other artifacts per se, but rather the kinds of exploration such goals lead workers to engage in which have important cognitive consequences.

The same situation applies to what we have been calling coordinated knowledge, or knowledge of how the two systems are related. This becomes clear when we look at the overlap between production and MRPII as a domain in itself; those who must explore this overlap in order to accomplish various tasks effectively develop a sophisticated coordinated model that they use implicitly. As with the development of an understanding of MRPII or production, this coordinated understanding is strongly shaped by an individual's job goals. Specifically, when the negotiation requires long-range goals, the individual comes to understand the relationship between the systems at the level of core organizing concepts. This is what occurs with Fred, Joe, Ronny and Sam. When the negotiation requires short-term trouble shooting, the understanding is most refined at the level of peripheral concepts and specific content. This is what occurs with Juan and Harriet.

In this study, these activity related factors clearly exert a more powerful influence on each individual's understanding than classroom-type education and length of time on the job. Although classroom training and years on the job factor in, (as we saw with Manual and Genevieve with work experience and Ben with classroom training), they are not the strongest influences in our study.

However, we cannot conclude at this point that job activity is inherently more instructive than classroom-type training for this kind of knowledge. Based on our observations of MRPII classroom settings (see description in Scribner et al., 1991), we can say that these classes do not emphasize goal oriented and constructive activities, but rather provide de-contextualized principles and formulas. It is difficult to say what individual learners glean from these classes. Our observations indicate that those with the most work experience were able to use the principles to pose problems for themselves. Like Genevieve and Manual (above) these students may have been able to make use of this past experience as a comparative empirical context. However, relative novices found much of the material inaccessible. Classroom training that employs more problem-oriented and constructive tasks that lead learners to explore and reconstruct the MRPII and production systems for themselves may have functionally equivalent educational value to comparable work experiences.

This study also provided an opportunity for the refinement and testing of a new method of analyzing speech data, long considered a rich source of data about how people conceptualize knowledge domains (e.g., see Ericsson and Simon, 1984, for discussion and review). The method refined for this study enabled us to analyze data both quantitatively and qualitatively and at two levels of detail, the level of "proposition" and the level of "stream". This method proved sensitive, reliable and flexible enough for a variety of different analyses, and rendered a rich profile of individual knowledge for each subject.

Analysis of Domains as Social Entities.

One of the most exciting advances refined here is use made of an analysis of knowledge systems first described in Scribner et al. (1991). In that paper we viewed knowledge domains as organized systems of knowledge with a prior social history and historical autonomy from individual knowers and proceeded to analyze these domains for their core concepts or key aspects. This kind of analysis, it was argued, could provide a useful analytic devise for studying individual understanding of target domains. In this study, our prior analysis of the two target domains proved valuable in two ways. First, our scheme of MRPII gave us an abstraction of an idealized expert's representation while the list of production concepts (and rules for their use) gave us a picture of the collective production knowledge at Kemps. These two broad models allowed us to locate an individual's notions within a larger collective (in the case of production) and render a picture of the depth and breadth of expertise (in the case of MRPII). This is an important methodological advance for research on historically newer domains; unlike physics or math, there are not well-defined texts identifying core concepts and the hallmarks of expertise are not well articulated.

MRPII as Theoretical Knowledge

The notion of MRPII as a "theory" in Vygotsky's and Davydov's sense was a critical presupposition to the above mentioned analysis. In our efforts to work within the tradition of Soviet activity theory, we have attempted to adopt the notion of "scientific concept" as it is elaborated by L.S. Vygotsky (1978, 1987) and more recently by V. V. Davydov (1984, 1988). In Davydov's work, a theoretical concept is "generative;" it is a system of relations between elements that can generate examples of its target. Davydov contrasted this with empirical generalization, an abstract notion that is gradually inferred through experience with actual objects. We realize that the characterization of MRPII as this kind of theory has its problems; interactive computer programs are rarely referred to as "theories," and most are actually theory driven tools or applications. However, when used as intended, MRPII is a kind of artificial intelligence system that generates predictions according to specific theoretical principles about the availability of resources and recommends actions based on its predictions. In this sense, it is a true instantiation of a theory. It cannot predict the future; rather it makes "guesses" according to algorithms with implicit theoretical assumptions. In its capacity as a predictor we feel that it is a theoretical system in Davydov's sense. That is, it is based on specific assumptions about the target domain and contains logic and algorithms which can work to generate examples in a way that Davydov (1988) describes.

If MRPII were a computerized instantiation of a theory, it would follow from Davydov's formulation that true expertise in MRPII would involve knowledge of both production and the formal MRPII logic, and an understanding of how the two relate in a specific setting. This would be similar to characterizing an expert in statistics as one who knows the mathematical assumptions underlying different methods and understands how different methods are appropriate for different data and questions.

Distribution of Knowledge in the Plant

The disturbing finding in this study is that all those who developed profiles of expertise held managerial positions. This raises the question that it was these subjects' high level of responsibility and decision making power which determined expertise. In addition, from these data we can only suggest that activity actually shaped our subjects' ways of understanding over time. Each of these individuals could have come to hold the jobs and roles that they do because of how they think about MRPII and production. For example, it would appear at first glance that managers possess the most expertise, and may therefore be more able to engage in activities that affect long range goals; their expertise may have been a prerequisite for this responsibility.

However, findings from previous work (Scribner et al., 1991) and the results shown in Table 6 suggest otherwise. First, Sam, Joe, Ronny and Fred were managers (at Kemps or another plant) before MRPII was introduced into their work place and the changes in their day to day activities coincided with their introduction to MRPII. Second, data from the comparison plant in our previous MRPII study (Scribner et al., 1991) did not show such a relationship between level of responsibility and expertise. In this second plant (Intek), material control and planning employees at all levels were compelled to engage in what we have called constructive activities and were trained not to execute procedures, but rather devise their own. Although the power structure in this plant is similar (with managers having final say on planning decisions), preliminary analyses reveal impressive levels of both production and MRPII understanding among employees at various levels.

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Table 1.

Tasks Performed by Subjects in Target Jobs Displayed According to Nature of Activity and Leading Activity Category

Leading Activity Categories	Nature of Activity Constructive	 Procedural
Supervising		
	Training	Evaluating Planning Decisions
	Supervising Shop Floor	Evaluating Shop Floor
	Supervising Planning	Supervising Stockroom
Troubleshooting		
	Negotiating Discrepancies Between Systems	Resolving Discrepancies
		a) in MRPII
	Implementing MRP	b) in Shop Floor Information
	Implementing Machines	Tracking Lost Parts
Information Handling		
	Generating Information	Gathering Information
	Developing Reports	Reviewing Information
	Conducting Meetings	Attending Meetings
	Coordinating MRP and Production Information	Verifying Information
		Issuing Parts
		Inventory Maintenance
		Negotiating with Customers
Scheduling		
	Machine Shop Scheduling	Order Release
	Job Shop Scheduling	Order Recommendation - manufactured parts
	Forecasting	
	Master Scheduling	
	Order Recommendation - Purchase Parts	

Table 2.

Coded Excerpts From Probe Interviews

Ben	Code
no, that's the perfect reason 1/ why you would not want the computer	NA
to release its own work orders 2/	MRPII
because in that case if you close out that work order 175 short 3/	MRPII
and it just released another work order for 175 4/	MRPII
even if you did have the components 5/	P
you would want to find out 6/	NA
what happened to make that thing 825 instead of 1000 7/	MRP
Helen	
sometimes I've found as much as 250 600 discrepancy on connectors 1/	P
sometimes just walking through like I was doing a couple months ago 2/	P
I just happened to walk through finished goods 3/	P
and my eyes are always wide open 4/	NA
but you know I looked at the box 5/	P
and I see 200 connectors sitting on the shelf 6/	P
that aren't on the tube 7/	MRPII
Ronny	
somebody put an order into the finished goods against the wrong manufacturing order 1/	P
they over ran it by 2000 against the old order 2/	MRPII
now this order is now 2000 short 3/	MRPII
but everybody thinks they've got 200 pieces of availability on the floor 4/	P
when they don't have them 5/	P
and they've committed them to a customer 6/	P
and now we have to scramble to make new parts 7/	P

Table 3.

Jobs and Proportions of MRPII and Production Talk in Streams

	Job Title	Proportions of Streams					
		MRP		Production		Total	
		%	(N)	%	(N)	%	(N)
Material Control Managers							
Fred	Mgr. Planning & Production Control	43.9	(25)	56.1	(32)	100	(57)
Sam	Supervisor of Planning	47.0	(24)	53.0	(27)	100	(70)
Ronny	Manager of Material Control	45.7	(32)	54.3	(38)	100	(51)
Planners							
Ben	End Item Planner	66.7	(40)	33.3	(20)	100	(60)
Genevieve	End Item Planner	36.0	(18)	64.0	(32)	100	(50)
Fay	End Item Planner	26.0	(13)	74.0	(37)	100	(50)
Jerry	End item Planner	13.8	(4)	86.2	(25)	100	(47)
Raymond	Component Planner	31.9	(15)	68.1	(32)	100	(31)
Manuel	Component Planner	38.7	(12)	61.3	(19)	100	(29)
Expediters							
Harriet	Expediter	41.9	(18)	58.1	(25)	100	(63)
Juan	Expediter/Machine Shop Scheduler	33.3	(10)	66.7	(20)	100	(31)
Production Managers							
Joe	Manager of Assembly	44.4	(28)	55.6	(35)	100	(12)
Helen Sup.	Manu'ing and Customer Service	29.0	(9)	71.0	(22)	100	(43)
Warren	Supervisor of Stockroom	8.3	(1)	91.7	(11)	100	(30)

Table 4.

Three Profiles of Work/Educational History and

MRP/Production Talk Results

Name	Education* School	Education* MRP	Job Title	Years of Work At Kemps / Total Manu'ing	Proportions of Streams MRP %	MRP (N)	Production %	Production (N)
Fred	HS	wks	Manager of Planning & Production Control	16/16	43.9	(25)	56.1	(32)
Ben	C	Cert	End Item Planner	1/8	66.7	(40)	33.3	(20)
Helen	HS	--	Supervisor of Manufacturing and Customer Service	11/11	29.0	(9)	71.0	(22)

* HS = High School
C = College
wks = *Some MRPII classes*
Cert = APICS certification

Table 5.

Proportions of Switching in MRP/Production Talk

Occupational Groups	Switching Proportions %	(N)	Total Streams %	(N)
Material Control Managers				
Fred	71.9	(41)	100	(57)
Sam	86.3	(44)	100	(51)
Ronny	62.9	(44)	100	(70)
Planners				
Ben	50.0	(30)	100	(60)
Genevieve	70.0	(35)	100	(50)
Fay	54.0	(27)	100	(50)
Jerry	24.1	(7)	100	(29)
Raymond	61.7	(29)	100	(47)
Manuel	67.7	(21)	100	(31)
Expediters				
Harriet	67.4	(29)	100	(43)
Juan	66.7	(20)	100	(30)
Production Managers				
Joe	71.4	(45)	100	(63)
Helen	51.6	(16)	100	(31)
Warren	0.0	(0)	100	(12)

Table 6.

Display of Subjects Who Produced Coordinated Streams on Probes 7 and 14

	Probe 7 Card Sort		Probe 14 MRP/Prod Synch	
	kind	(%)	kind	(%)
Material Control Managers				
Fred	C	27	C	28
Sam	L	15	C	30
Ronny	L	8	F	20
Planners				
Ben	C	28	-	
Genevieve	-		F	40
Jerry	-		-	
Fay	-		F	30
Raymond	-		-	
Manuel	L	33	F	31
Expediters				
Harriet	L	15	F	42
Juan	-		F	20
Production Supervisors				
Joe	L	71	C	35
Helen	-		-	
Warren	-		-	

key:
C produced core conceptual, local conceptual + functional streams
L produced local conceptual + functional coordinated streams
F produced only functional coordinated streams
- produced no coordinated streams

Table 7.

Individual Sorting Strategies on Probe 7 Card Sorts

	SORT 1			SORT 2		
	Entry	Domain	Scheme	Entry	Domain	Scheme
Fred	level	MRP	hierarchy	process	P	sequence
Sam	level	MRP	hierarchy	level	P	make/buy
Ronny	part	P	make/buy	process	P	pack/assy
Ben	level	MRP	hierarchy			
Genevieve	part	P	pack/assy	part	P	sequence
Fay	part	P	pack/assy	level	P	sequence
Jerry	part	P	pack/assy	process	P	sequence
Raymond	part	P	sequence	part	P	make/buy
Manuel	part	P	make/buy	level	MRP	hierarchy
Harriet	level	P	sequence	process	P	sequence
Juan	part	P	sequence	part	P	sequence
Joe	process	P	pack/assy	process	P	sequence
Helen	process	P	pack/assy	part	P	sequence
Warren	process	P	pack/assy	process	P	sequence

key

Entry Points:

level	Relative level of item in MRP hierarchy
part	Part name or number
process	Operation or assembly in production

Domains:

MRPII	MRPII
P	Production

Leading Schemes:

sequence	Operational sequence-based sort
make/buy	Make/buy part category-based sort
pack/assy	Packing/assembly process category-based sort
hierarchy	MRPII hierarchy sort

Table 8.

Summary of Results from Tables 3, 5, 6, and 7

	1. % of Talk		2. Switching	3. Coordinated		4. Sort		5. Education		6. Yrs Exp
	MRP	Prod	Proportion of talk	7	14	1	2	Schl	MRP	@K/Tot
Material Control Managers										
Fred	43.9	56.1	71.9	C	C	M	P	HS	wks	16/16
Sam	47.0	53.0	86.3	L	C	M	P	>C	Cert	3/7
Ronny	45.7	54.3	62.9	L	F	P	P	<C	3	14/15
Planners										
Ben	66.7	33.3	49.2	C	-	M	-	=C	Cert	1/8
Genevieve	36.0	64.0	70.0	-	F	P	P	HS	wks	23/23
Fay	26.0	74.0	54.0	-	F	P	P	HS	wks	6/6
Jerry	13.8	86.2	24.1	-	-	P	P	HS	wks	8/8
Raymond	31.9	68.1	61.7	-	-	P	P	<C	wks	5/9
Manuel	38.7	61.3	67.7	L	F	P	M	HS	wks	7/13
Expediters										
Harriet	41.9	58.1	67.4	L	F	P	P	=C	wks	10/10
Juan	33.3	66.7	66.7	-	F	P	P	<C	wks	3/5
Production Managers										
Joe	44.4	55.6	71.4	L	C	P	P	HS	2	28/38
Helen	29.0	71.0	51.6	-	-	P	P	HS	-	11/11
Warren	36.0	64.0	0.0	-	-	P	P	<C	-	8/17

key:

3. Coordinations
    - C — produced core conceptual, local conceptual & functional coordinations
    - C — produced local conceptual + functional coordinations
    - F — produced only functional coordinations
    - - — produced no coordinated streams
4. Card Sorts
    - M — produced MRPII card sort arrangement
    - P — produced Production based card sort arrangement
5. Education
    - School
        - HS — completed high school
        - <C — some college
        - =C — completed college
        - >C — completed courses or degrees beyond college
    - MRPII Education
        - wks — MRPII workshops, by vendor or in house
        - Cert — APICS certified (passed 5 courses)
        - # — number of APICS/MRPII courses taken
        - - — no MRPII courses
6. Years Experience in Manufacturing
    - @K/Tot — years worked at Kemps Electronics over total years in manufacturing

Table 9.

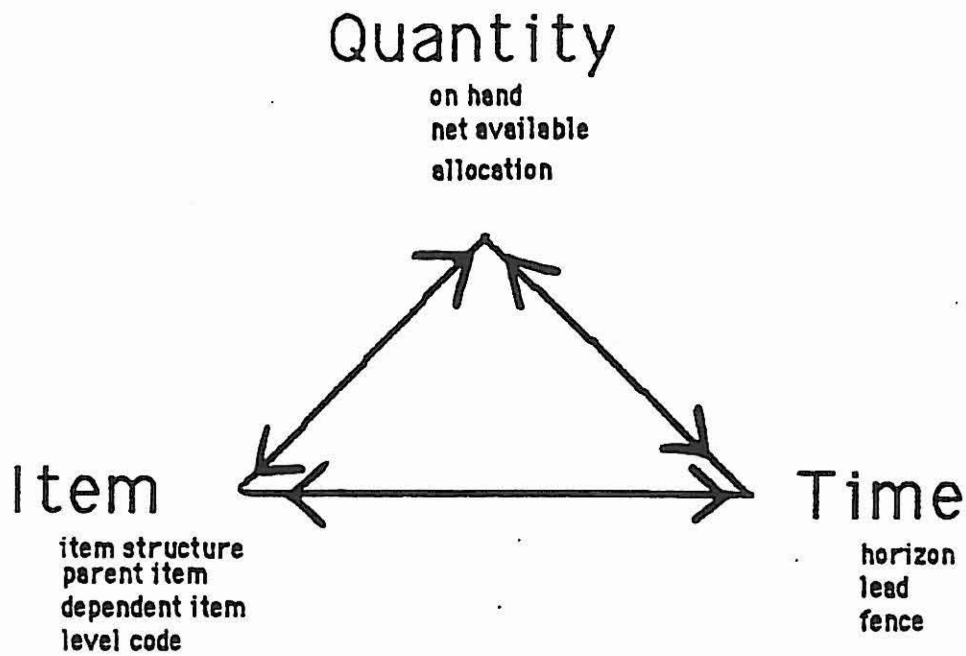
Individuals' Constructive and Procedural Job Activities

	Workers													
Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Constructive														
Supervision	X	X	X	X										
Troubleshooting	X	X	X	X	X	X	X	X						
Information	X	X	X	X	X	X								
Scheduling	X	X		X				X	X	X				
Procedural														
Supervision	X	X		X		X								
Troubleshooting		X	X	X	X		X	X	X	X	X	X	X	X
Information				X	X	X	X	X	X	X	X	X	X	X
Scheduling							X	X	X	X	X	X	X	X

1 - Fred
2 - Sam
3 - Ronny
4 - Joe
5 - Helen
6 - Warren
7 - Harriet
8 - Juan
9 - Manuel
10 - Raymond
11 - Ben
12 - Genevieve
13 - Fay
14 - Jerry

Figure Caption

Figure 1. Three core organizing MRPII concepts with and without subconcepts.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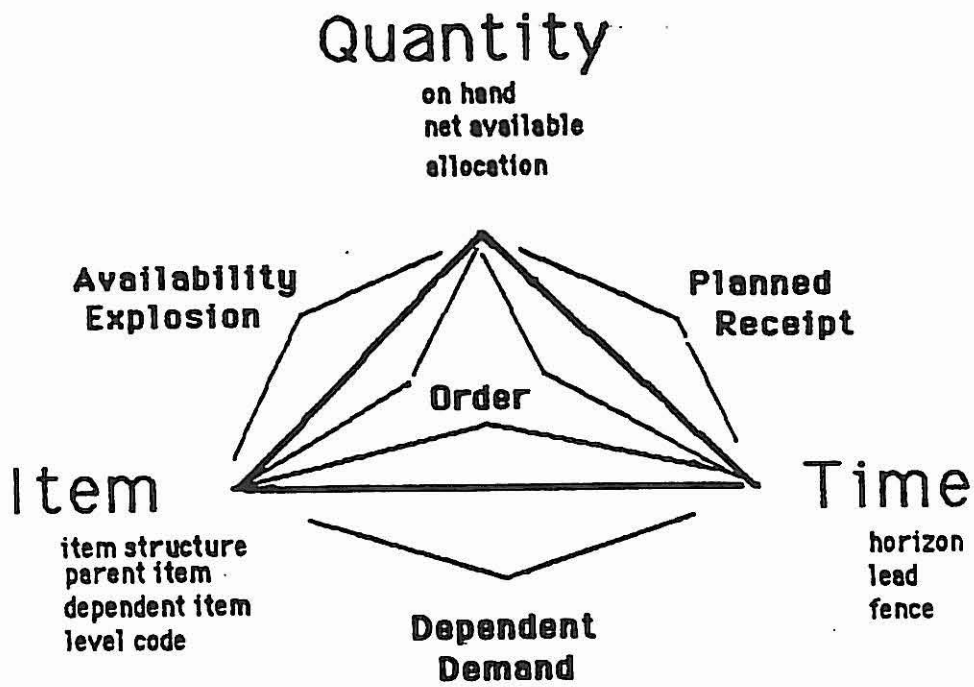
on hand
net available
allocation
Item
item structure
parent item
dependent item
level code
Time
horizon
lead
fence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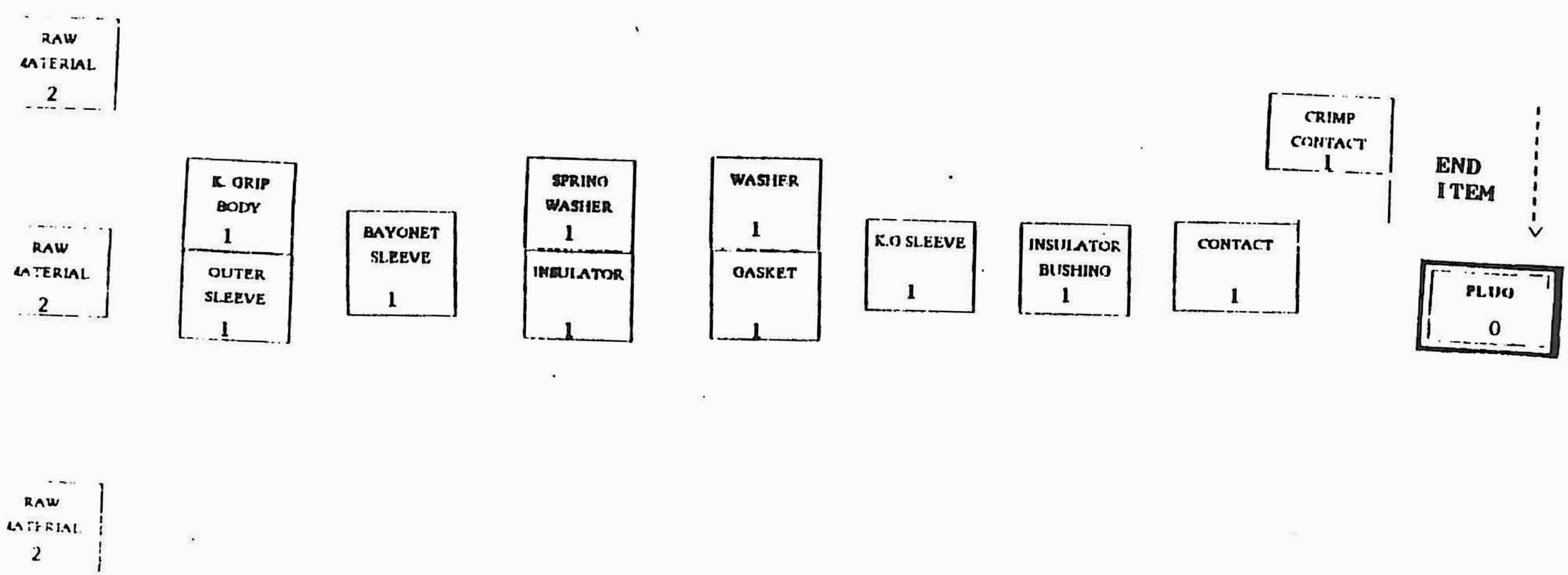
Item
item structure
parent item
dependent item
level code
Time
horizon
lead
fence
Dependent
Demand

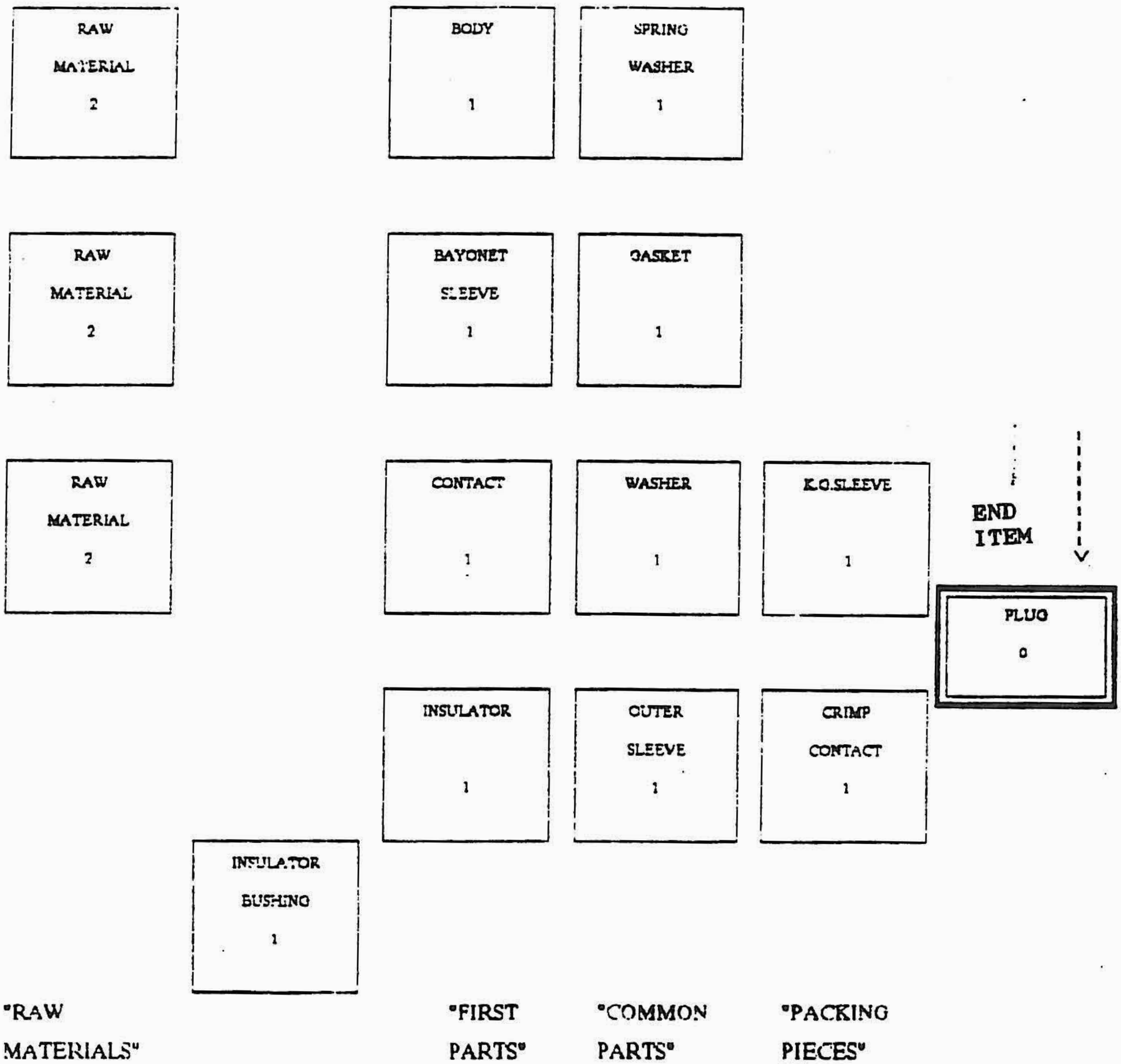
Figure Caption

Figure 2. Sorting according to a linear processing sequence, a production-based part grouping, and an MRPII end-item hierarchy.

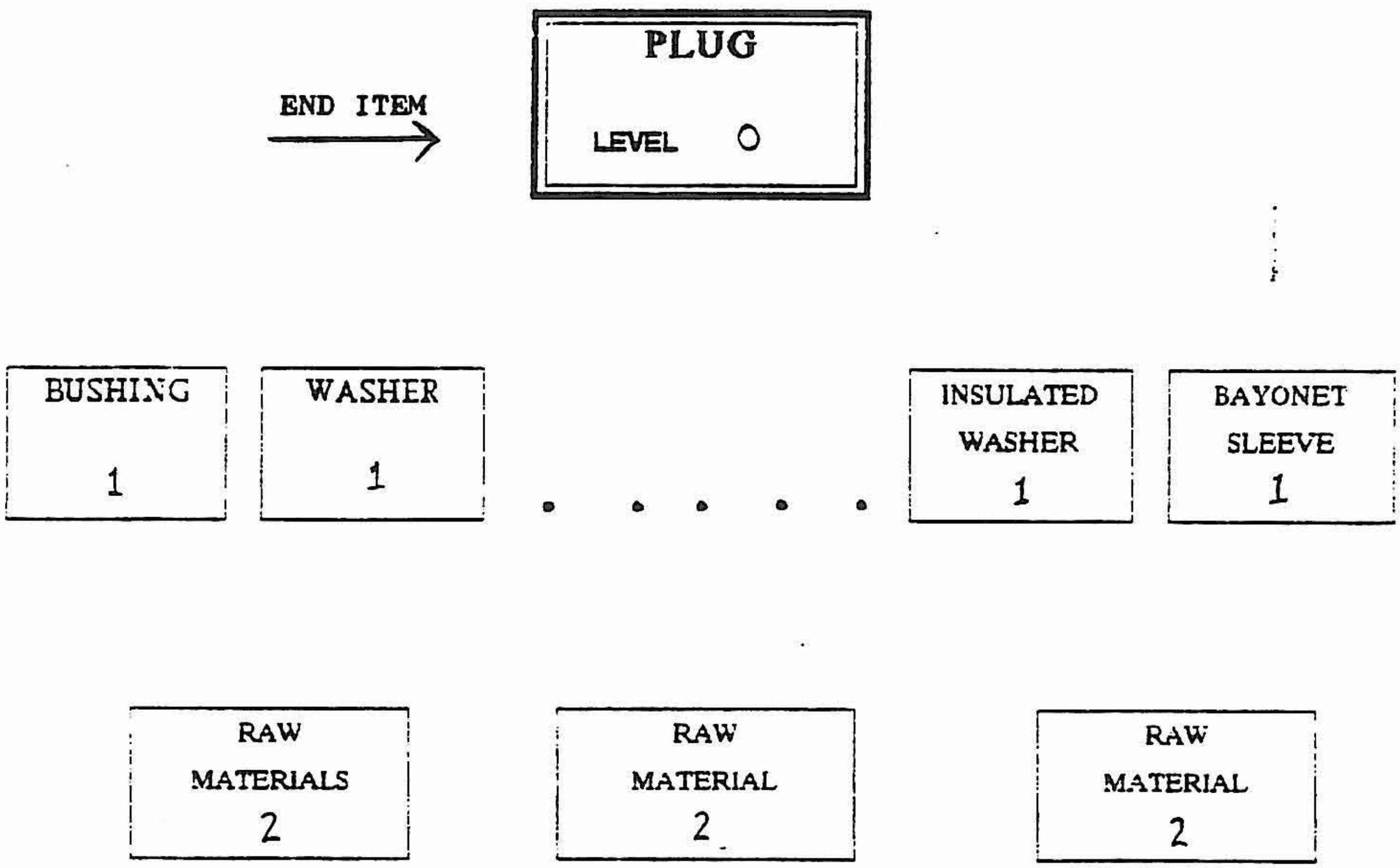
PRODUCTION SORT



GROUPING SORT



MRP SORT


END ITEM
PLUG
LEVEL O
BUSHING
1
WASHER
1
INSULATED
WASHER
1
BAYONET
SLEEVE
1
RAW
MATERIALS
2
RAW
MATERIAL
2
RAW
MATERIAL
2

Appendix 1: Job descriptions of each subject

Fred is the Manager of Planning and Production Control. His job is centralized in the production and material control room, and he communicates with individuals in various functions in and out of the plant. He generates reports that integrate and map out many levels of information (inventory, production, planning, and finance) and these reports are used both as tools in the plant and also as a backup information system when the computer goes down. He negotiates with customers, vendors, and plant personnel and management, conducts weekly production meetings among planners and managerial personnel from material control and the shop floor and works through problems of plant organization, such as the company's implementation of MRPII. As the primary organizer of the control and information operations of the plant, he negotiates long range plans and goals with the ongoing status of orders in production. For instance, he evaluates the weekly recommendations made by component planners for the purchase of parts in terms of larger plant finance and vendor issues and also in terms of planners' job performance.

Sam is the of Planning. He supervises a planning group consisting of three product-line based planning teams, each comprised of an end item planner and a component planner. His activities include establishing forecasts based on past usage information and projected markets, coördinating and evaluating the planner group activities, conducting weekly meetings with planners to discuss the status of their products and orders, training new planners, and troubleshooting planning problems that arise. His work is done mostly through the computer, through negotiations with planners and with Fred, who is his liaison to larger plant issues and domains.

Ronny is the Manager of Materials, a job that involves trafficking from the material and production control room to his managerial domains, the component and finished goods stockrooms. He negotiates the status of company inventory, resolves inventory discrepancies between actual stock counts and the MRPII information, and troubleshoots inventory problems, particularly at months' ends, when most large orders are shipped from end item stock. His job primarily involves negotiations with people in the plant and considerable use of the MRPII system in relation to the status of parts in stock.

Joe is the Manager of Assembly. He is the primary organizer of shop floor processing and production of finished goods. He establishes daily priorities of jobs in relation to orders released by planners, production constraints of capacity, part shortages, and the actual conditions of orders, workers and machines on the floor. He oversees all of the production personnel as well as training new shop floor workers. He also orchestrates the changes in shop floor technology, for instance in the recent transition from assembly line format to production cells or clusters. He uses the MRPII system minimally, and does most of his job on the production floor.

Helen works closely with Joe in assembly, as the of Expediting and Customer Service. She spends her time continually touring the various work centers of the shop floor, gathering information about the ongoing process status of parts and orders in relation to customer needs. She is the liaison between the shop floor, sales and production control. Her job involves expediting hot orders for customers, de-expediting other orders on the floor, locating lost parts, anticipating problems and schedules, and notifying people in sales, dispatch, and shop floor work centers of up to the minute needs. She uses the MRPII system to verify accuracy of information from other sources, but her primary information comes from paper, people and the parts themselves.

Warren is the stockroom. His job involves the supervision of several material handlers and the maintenance of physical inventory in the component stockroom, in which thousands of parts are kept in different states of processing. He works intimately with the parts themselves in the daily issue of parts to orders and in regular stock counts. He is also responsible for the maintenance of stock records and for tracking lost parts in stock when discrepancies occur between the actual physical count and the record count. Although this involves minimal use of the MRPII system in order to check quantities, the primary representational tool used in the stockroom is the "bin card" which is an ongoing pen and paper history of all part transactions for each component.

Planners work in teams comprised of one end item planner and one component planner, coupled by common product lines. This means that the component planners release orders for parts that will be needed in the finished good production planned by their respective end item planning partners. The main activity of all planners is order launching or releasing, which involves reviewing information about availability of parts and order demands to determine the validity of recommendations generated by MRPII in order to plan, release, cancel or defer orders. They also review delivery requests from sales in order to establish promise dates. They attend production meetings with material control and shop floor management (in which schedules are renegotiated) and do some shop floor expediting by phone. Planners use a variety of reports on part and order status and history of usage as well as the MRPII system in reviewing and releasing orders. Though planners share the primary responsibility of order release, end item and component planners' activities differ in significant ways. End item planners schedule the assembly of finished goods being made in-house and shipped out to customers, a job done routinely through the computer system with some information from paper reports. Component planners schedule parts that are machined in-house in a similar way to end item planning, but they also recommend the purchase of components from vendors. This activity differs significantly from in-house production planning, because recommendations are made on "planned review sheets", to be evaluated by Fred (see final report for detail). This activity involves coordinating information from the computer and from reports and explicitly justifying recommendations made.

The two expediters are centralized in the material and production control room and travel from there to the shop floor regularly to expedite orders. Harriet is the expediter for end items, particularly for government orders, which are high priority at Kemps; she works mainly with expedite request sheets to reschedule delivery promise dates and production dates based on information from MRPII and the shop floor. Juan is the expediter and machine shop scheduler for components; he travels between production control, where he works through the MRPII system, and the component machine shop, where he schedules the manufacture of components based on machine constraints and upcoming demands and expedites orders in process.

Appendix 2: Example Probes

Probe 1. Present actual finished part to planner (KC-59-154).

Can you tell me the parts that make up this item?

[ask for alternative depending on response]

Can you tell me how this is made?

Probe 7. Give planners cards representing components.

These cards have the numbers and names of parts on them. Look them over and then lay out the cards to make an end item.

Is there another way of doing it?

Probe 8. Can you tell me what it takes to make a finished good?

Tell me what's involved from beginning to end.

(If the planner asks how you want it represented, indicate "however you want."

Probe 14. What are some of the reasons Mapics can get out of synch with production, (or what's going on on the shop floor)?

Followup: Can there be discrepancies between production and Mapics?

What, for example?