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A Decade of Innovation in Particleboard and Composite Materials: a content analysis of Washington State University's *International Particleboard/Composite Materials Symposium Proceedings*

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Abstract

The authors investigated the typology and characteristics of recent technology innovation in particleboard and composite materials. Conducting a cluster analysis of data derived from a content analysis of the *International Particleboard/Composite Materials Symposium Proceedings*, they identified four major clusters of like-type technology innovations – *manufacturing*, *high technology*, *materials processing*, and *new products*. *Equipment makers* dominated innovation in all four clusters, and "improved product quality" was the predominant source of economic benefits.

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Innovations in the *manufacturing* cluster are characterized as process innovations originated by an *equipment maker*. *Equipment makers* provided specific technology, but participation by *manufacturers* was not unusual. There was no participation by end-users. After "improved product quality," "reduced energy consumption" was most often cited as a source of economic benefits. *High technology* innovations are characterized as process innovations originated by an *equipment maker* that provided specific technology. There was no participation by a *manufacturer* or *end-user*. In general, *equipment makers* were technology leaders, sometimes involving themselves in particleboard and composite materials production processes for the first time. "Improved product quality" was the predominant source of economic benefits. *Materials processing* innovations are characterized as process innovations originated by an *equipment maker*. There was significant *manufacturer participation* and no participation by *end-users*. After "Improved product quality," "substitution of inexpensive for expensive raw materials" and "reduced environmental impacts," were jointly cited as sources of economic benefit. *New products* innovations are characterized as product or combination product/process innovations originated by an *equipment maker* or jointly with an *equipment maker* and a

manufacturer both providing specific technology. *End-user* participation was not unusual. After "improved product quality," "better fits for customer end uses and processes" and, jointly, "more effective use of raw materials" and "substitution of inexpensive for expensive raw materials" predominated as sources of economic benefits.

Citing the Utterback-Abernathy model of technology innovation, the authors anticipate continued equipment maker innovation in the form of improved automation and continuous processing.

Introduction

The transformation of the forest products industry by engineered wood has been discussed for over twenty years. A literature search revealed that as early as 1982, using the Fisher-Pry technique (Fisher and Pry 1971), Montrey (1982) forecast rapidly increasing demand for waferboard/oriented strand board (OSB) and, ultimately, the complete substitution of waferboard/OSB for plywood in the U.S. structural panel market.

By the mid-1990s America's old-growth forests were almost gone, timber supplies from public forests were severely constrained, and the renewable forest resource consisted of second- and third-growth trees managed under sustainable forestry practices. Larger trees were becoming scarce, and industry analysts concluded that engineered wood products manufactured from underutilized species and small diameter trees represented the future of the wood products industry (Guss 1994; Smulski 1997). By 1999, engineered wood products outsold dimensional lumber by volume (APA 2002).

Although the market penetration of engineered wood was in full swing by the 1990s, product innovation in engineered wood had already been under way for forty years. Wood technologists had known for decades that particle-based panel and structural products could be produced which would achieve the physical and mechanical properties of plywood and dimension lumber. Waferboard, COM-PLY^tm^, and OSB have been produced commercially since the 1960s, 1970s, and 1980s, respectively. Commercial production of laminated veneer lumber (LVL) began in 1974. Parallel strand lumber (PSL) went into commercial production in 1988 and laminated strand lumber (LSL) in 1990.

The authors were interested in the typology and characteristics of technology innovation, including process innovation, that has accompanied the market penetration of engineered wood. Although a literature search revealed many descriptions of individual innovations, with the exception of Juslin and Hansen (2002), who suggested that product development efforts in the Finnish forest industries have been driven by economic benefits of various types, no research was identified on the typology or characteristics of this innovation.

Research in Technology Innovation

It is fair to say that research on technology innovation has been full of ideas but has lacked conceptual and definitional consistency. Calantone et al. (1995) searched the academic literature and compiled a list of 40 fundamental principles of new product development, categorizing these principals as relating to product innovation, new product development and launch, product diffusion, and marketing/R&D interface. In a study of technology innovation typology Garcia and Calantone (2002) identified 15 constructs and 51 distinct scale items that had been used in just 21 empirical studies of new product development. They surveyed new product practitioners and found strong overall agreement that these principles were either usually or almost always true. Given so many conceptual possibilities, the task of developing a few general variables with which to characterize descriptions of individual engineered wood innovations was an issue for the authors. After assessing a variety of proposed principles of technology innovation, the authors developed a descriptive scheme based on the work of Utterback (1996), Von Hipple (1988), Rogers (1983), and Juslin and Hansen (2002). Their well-researched paradigms[1] of technology innovation type, source, diffusion, and the source of economic

[1] Using the Kuhn (1970) definition.

benefit seemed consistent with the information generally present in descriptions of individual engineered wood innovations.

Utterback suggested a three-phase model of innovation dynamics. In the earliest, fluid phase, the emphasis is on product change. Functional product performance is the basis for competition. Then, if the market for a new product grows, the industry may enter a transitional phase in which competitive emphasis is on producing products for more specific users, as the needs of those users become more clearly understood. Product and process innovations become more tightly linked. Expensive specialized production equipment appears, often as islands of automation. Finally, if the market for the product continues to grow, the industry may enter a specific phase in which process improvements become the exclusive focus of innovation. Competition comes to be based on the value ratio of quality to cost, and extremely close linkages exist between product and process changes. For Utterback, the key concept is the type of innovation. Is an innovation a product innovation or a process innovation?

Von Hipple explored the functional source of new product innovation. He found that the sources of new product innovation in some industries typically originated with end users. In other industries, manufacturer innovation was predominant. For von Hipple, the question is who innovates, and he concluded that innovating firms could reasonably anticipate higher profits from an innovation than non-innovating firms could.

Rogers described technology diffusion as the process by which innovation is communicated through channels, over time, and among the members of a social system. Two of Rogers' concepts are "compatibility" and "complexity," the degree to which an innovation is perceived as being consistent with the existing knowledge, values, experiences, and needs of potential adopters and the degree to which an innovation is perceived as difficult to understand and use, respectively. Rogers concluded that compatible innovations diffuse more quickly than non-compatible innovations and that the complexity of an innovation is negatively related to its rate of adoption.

Juslin and Hansen suggested a set of six economic benefit variables as the drivers of product development efforts in the Finnish forest industries: "more effective use of raw materials," "substitution of inexpensive for expensive raw materials," "improved product quality," "reduced environmental impacts," "reduced energy consumption," and/or "better fits for customer end uses and processes."

Methods and Analysis

Washington State University's *International Particleboard/Composite Materials Symposium Proceedings* is a systematic source of descriptions of engineered wood innovations.[2] The authors conducted a contingent, qualitative content analysis of ten years (1992-2001) of articles published in the *Proceedings* in order to develop systematic data based on operationalizations of paradigms suggested by Utterback, von Hipple, Rogers, and Juslin and Hansen. Though not a complete catalog of all innovations, the *Proceedings* are the preeminent forum for discussion of particleboard and composite materials innovation. Content analysis was chosen because it is especially appropriate to

[2] The authors began with bibliographic database searches on a series of key words, including "engineered wood", "wood composite", and a list of engineered wood products. Articles were identified from a number of sources, including the *Canadian Journal of Forest Research*, *Wood & Fiber Science*, *Forest Science*, *Wood Science*, *Journal of Wood Chemistry & Technology*, *Bioresource Technology*, *Wood Science and Technology*, and *Journal of Wood Science*. However, only Washington State University's *International Particleboard/Composite Materials Symposium Proceedings* and *Forest Products Journal* were the sources of more than three or four articles. After reviewing a sample of articles, the authors concluded that 1) the *Proceedings* stood alone as an extensive source of information or the type they were looking for and 2) database search facilities were inadequate for identifying a complete set of articles. It would be necessary to review every article in a journal of interest that appeared during the designated time period. The only source that appeared to be a rich enough source to merit such an effort was the *Proceedings*.

investigations in which data accessibility is a problem (Holsti 1969). The authors did not have access to primary data on innovations in engineered wood nor did they have the resources to develop primary data.

Krippendorff (1980) identified Berelson (1952) as one of the first integrated presentations of content analysis. Based on his review of the technical literature, Berelson proposed the following definition: “Content analysis is a research technique for the objective, systematic, and quantitative description of the manifest content of communication.” The syntactic-and-semantic requirement limits the analysis to the manifest content of the communication. Objectivity requires that “the categories of analysis should be defined so precisely that different analysts can apply them to the same body of content and secure the same results.” The system requirement mandates that “all of the relevant content is to be analyzed in terms of all the relevant categories, for the problem at hand” and also that the data be relevant to a scientific problem or hypothesis. The quantification requirement means that the analysis must concern itself with the extent to which the analytic categories appear in the content and that the analysis must be amenable to statistical methods, although the data need not be numeric. A qualitative content analysis is based on the presence-absence of particular content (Berelson 1952; Holsti 1969).

The authors reviewed ten years (1992-2001) of articles published in the *Proceedings*, analyzing all of the articles describing new materials, methods, equipment, or products applied in or resulting from commercial production of particleboard and/or composite materials. Articles describing non-commercial and pre-commercial innovations and other types of research were not analyzed. This is referred to as a contingent content analysis. Seventy-five articles were analyzed, collectively describing forty innovations. The authors characterized each innovation with respect to type of innovation (Utterback) and source of innovation (von Hipple). The articles rarely included descriptions that permitted the direct characterization of innovations with respect to compatibility and complexity (Rogers). However, the articles did describe participants in the innovations and their roles with respect to providing technology inputs. In the authors' view, participants providing specific technology inputs worth describing by a *Proceedings* author would be expected to be highly compatible with the innovation's technology. A participant whose role with respect to technology input was not described would be expected to be less compatible with the innovation's technology. Non-participants in the innovation would be expected to be even less compatible with the innovation's technology. Finally, the authors characterized the sources of economic benefit from adopting an innovation using the Juslin and Hansen findings. Thus, each innovation was characterized as:

- Initiated by an *equipment maker*, a *manufacturer* and/or an *end-user*,
- A *product innovation* and/or a *process innovation*,
- Having *high*, *medium*, or *low compatibility* for the *equipment maker*, the *manufacturer*, and the *end-user*, and
- Having economic benefits resulting from "more effective use of raw materials," "substitution of inexpensive for expensive raw materials," "improved product quality," "reduced environmental impacts," "reduced energy consumption," and/or "better fits for customer end uses and processes."

The authors refer to the resulting source, type, and compatibility variables as *technology variables* and to the source of economic benefit variables as the *economic variables.* See Table 1. The coding was completed in a binomial format, and for the sake of consistency, a single researcher conducted the coding.

Variable Type	Variables
Source	equipment maker, manufacturer, and/or end-user
Type	product innovation and/or process innovation
Compatibility Equipment Maker Manufacturer End-User	 high, medium, or low high, medium, or low high, medium, or low
Economic Benefit	more effective use of raw materials, substitution of inexpensive for expensive raw materials, improved product quality, reduced environmental impacts, reduced energy consumption, and/or better fits for customer end uses and processes

TABLE 1: VARIABLES

Of the 40 innovations identified, 22 innovations, described in 44 articles in the *Proceedings*, had complete information. See Table 2 for a list of the innovations for which complete information was available.

Innovations
Agrofiber furnish (#16)
Bio-catalytic system (#5)
Blending control system (#4)
Cement-bonded board (#14)
Closed-loop gasification system (#6)
Continuous pressing - particleboard, MDF (#1)
Continuous pressing – OSB (#2)
Continuous pressing – LVL (#3)
Conveyor drying of OSB (#7)
Emulsifiable pMDI for MDF (#13)
Formaldehyde scavenger post-treatment (#19)
Gypsum fiberboard (#15)
High power refining of MDF furnish (#18)
Mechanical forming (#22)
Near-infrared reflection (NIR) moisture sensors (#11)
On-line stiffness testing (#8)
RF curing of LVL (#20)
Ring flaker (#12)
Ultrasonic veneer grading (#9)
Urban wood (#17)
Wood-plastic composite (#21)
X-ray measurement of density profiles (#10)

TABLE 2: TECHNOLOGY INNOVATIONS WITH COMPLETE DATA

Having no *a priori* hypothesis about innovation in engineered wood or, more specifically, particleboard and composite materials, the authors performed a cluster analysis. Cluster analysis algorithms are designed to organize observed data into meaningful structures or taxonomies, permitting the generation of hypotheses about those structures (Anderberg 1973).

Using the technology variables,[3] the authors performed[4] *polythetic agglomerative hierarchical cluster analysis* on the 22 innovations with complete information. This technique first assigns each entity (i.e., innovation) to its own cluster in an *N*-dimensional

[3] The authors chose to use only the technology variables in the cluster analysis because these variables are based on general paradigms of technology innovation, unlike the economic variables, which are specific to forest industries.
[4] The software used was provided by Fernando Cinquegrani (http://www.prodomosua.it), a Microsoft Excel add-in, and SPSS 11.0 (http://www.spss.com).

space. Each axis is defined by one of the *N* number of variables used as the basis of the clustering. Then, these clusters are agglomerated on the basis of their distances from each other in the *N*-dimensional space, creating a hierarchy of larger and larger clusters until a single cluster contains all of the entities (McGarigal et al. 2000). The analysis associates the variables into clusters. No causal or independence/dependence relationships are assumed. The approach permits a single analysis to be viewed at several levels of detail and allows the analyst to determine the level of clustering that is significant.

Cluster Analysis Results

The dendrogram in Figure 1 presents the results of the "average linkage" (a.k.a. "between group linkages") fusion, using Euclidian distance, which was employed because it is the most commonly used fusion strategy (McGarigal et al. 2000). Choosing the level of clustering that was thought to be significant, the authors identified four major clusters, as shown in Figure 1, naming them *manufacturing*, *high technology*, *materials processing* and *new products* to reflect what appeared to be the themes of the clusters. In the first branching of the hierarchical tree-clustering, gypsum fiberboard and cement-bonded board separate from the other innovations. Then, wood-plastic composite separates. Fiberboard, cement-bonded board, and wood-plastic composite were included in the *new products* cluster. The next branching separates the *materials processing* cluster of innovations from the remaining innovations. Finally, *manufacturing* cluster innovations separate from *high technology* cluster innovations.[5]

[5] The high technology cluster might have been referred to as the high technology manufacturing cluster because this cluster is clearly dominated by high technology manufacturing innovations. However, the presence of the ring flaker, a materials processing innovation, suggested otherwise.

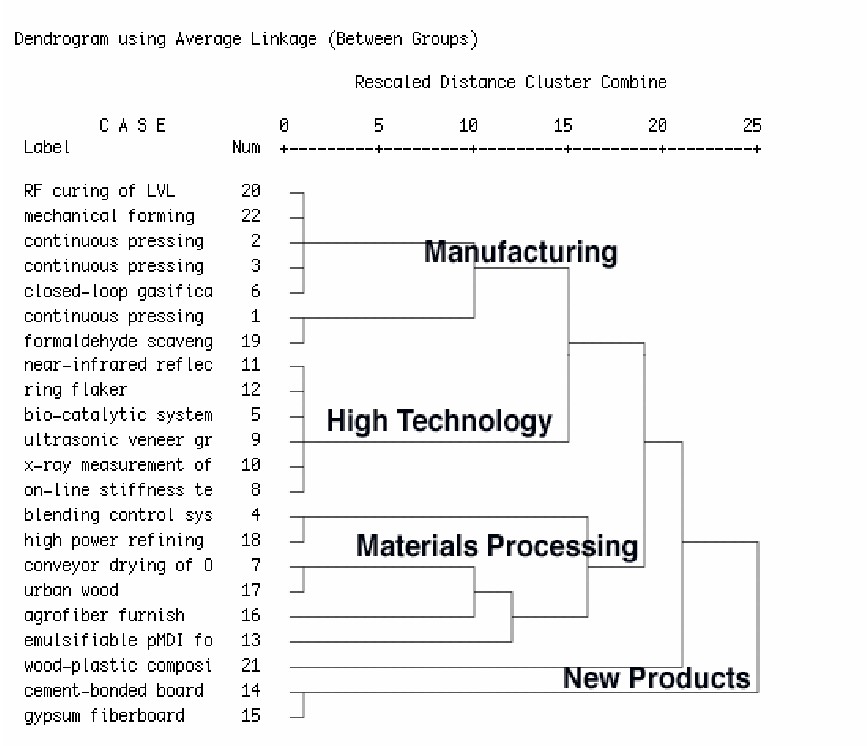

FIGURE 1: INNOVATION CLUSTERS

In order to assess cluster membership stability across clustering algorithms, the authors also applied “single linkage (a.k.a. “nearest neighbor”) and “complete linkage” (a.k.a. “furthest neighbor”) clustering approaches and Euclidian and squared Euclidian distance parameters. These alternative approaches very substantially agreed on cluster membership, indicating a pronounced structure to the data. The only differences in cluster membership result from the “complete linkage” method in which the wood-plastic composite separates as its own cluster in the third branching along with the *manufacturing* (mfr) and *high technology* (hi tech) clusters rather than the in the second branching.

Cluster Profiles

The non-parametric, binomial test procedure (Cochran 1977; Mendenhall et al. 2006) was used to screen the variables individually and in combination before using variable frequencies to profile the clusters. The binomial test compares the observed frequencies of the two categories of dichotomous variables to the frequencies expected under a binomial distribution with a specified probability parameter.[6] Only those variables with small significance levels (<0.10)[7] were used in the profiles. See Table 3.

Variable	Significance
Product Innovation	0.001
Process Innovation	0.000
Product & Process Innovation	0.000
Equipment Maker Innovation (EQUIP)	0.000
Manufacturer Innovation (MFR)	0.286
End-User Innovation (USER)	0.000
EQUIP & MFR Innovation	0.134
EQUIP High Compatibility (high)	0.286
EQUIP Moderate Compatibility (mod)	0.286
EQUIP Low Compatibility (low)	0.000
MFR High Compatibility (high)	0.000
MFR Moderate Compatibility (mod)	0.523
MFR Low Compatibility (low)	0.286
USER High Compatibility (high)	0.000
USER Moderate Compatibility (mod)	0.000
USER Low Compatibility (low)	0.000
EQUIP high & MFR high Compatibility	0.000
EQUIP high & MFR mod Compatibility	0.134
EQUIP high & MFR low Compatibility	0.052
EQUIP mod & MFR mod Compatibility	0.052
EQUIP mod & MFR low Compatibility	0.000
MFR mod & USER mod Compatibility	0.000
MFR mod & USER low Compatibility	1.000
More Efficient Use of Raw Material (Raw Mat'l)	0.523
Substitution for Expensive Raw Material (Substitute)	0.134
Improved Product Quality (Quality)	0.052
Reduced Environmental Impacts (Environ)	0.832
Reduced Energy Consumption (Energy)	0.004
Better Fits for Customer... (FIT)	0.001
Raw Mat'l & Substitute	0.004
Raw Mat'l & Environ	0.000
Substitute & Environ	0.004

TABLE 3: BINOMIAL TEST RESULTS

[6] This two-tailed test distinguishes between variables with a high probability of having been produced by a random process and variables that are frequent enough or rare enough to have a low probability of having been produced by a random process. Here the probability parameter was specified as 0.5. The hypergeometric probability, applied when the population is very large relative to the sample, was not used because the sample size was > 17 (Lindley and Scott 1995).

[7] The largest significance level that met this test was 0.052.

The authors found, as shown in Table 4, that the innovations in the *manufacturing*, *high technology*, and *materials processing* clusters were all process innovations. All of the innovations in the *new products* cluster were product innovations or joint product/process innovations.[8]

	Product	Process	Prod&Proc
Manufacturing (n=7)	0	7	0
High Technology (n=6)	0	6	0
Materials Processing (n=6)	0	6	0
New Products (n=3)	3	1	1

TABLE 4: INNOVATION TYPE BY CLUSTER (frequency)

As shown in Table 5, *equipment makers* (EQUIP) predominated as innovators.[9] *End users* (USER) were never an innovation source.

	Equipment maker	End user
Manufacturing (n=7)	7	0
High Technology (n=6)	6	0
Materials Processing (n=6)	5	0
New Products (n=3)	3	0

TABLE 5: INNOVATION SOURCE BY CLUSTER (frequency)

As shown in Table 6, the authors found that compatibility was never low for *equipment makers,* was never high for *manufacturers* except in the new products cluster where high equipment maker and high manufacturer compatibility were paired, and always low for *end-users* except in the new products cluster. It appears that *equipment maker*[10] innovators were the masters of high technology. In all of the high technology cluster innovations, high *equipment maker* compatibility was paired with low *manufacturer* and

[8] An innovation can be a product innovation, a process innovation, or both.
[9] Manufacturers (MFR) innovated individually and jointly with equipment makers. However, the significance levels of manufacturer variable were not small enough to pass the screen.
[10] They were also often new to forest products production, especially in the high technology cluster.

end-user compatibilities. The materials processing and new products clusters were marked by joint moderate compatibilities by *equipment makers* and *manufacturers*, and the new products cluster was marked by joint moderate compatibilities by manufacturers and end-users.

	EQUIP	MFR	USER			EQUIP &MFR	EQUIP &MFR	EQUIP &MFR	EQUIP &MFR	MFR &USER
	low	high	high	mod	low	high /high	high /low	mod /mod	mod /low	mod /mod
Manufacturing (n=7)	0	0	0	0	7	0	0	0	0	0
High Technology (n=6)	0	0	0	0	6	0	6	0	0	0
Materials Processing (n=6)	0	0	0	0	6	0	0	4	2	0
New Products (n=3)	0	1	0	2	1	1	0	2	0	2

TABLE 6: INNOVATION COMPATIBILITY BY CLUSTER (FREQUENCY)

As shown in Table 7, "Improved product quality" predominated as an economic benefit. In the *manufacturing* cluster, "reduced energy consumption" was also a significant source of benefits. Jointly, "substitution of inexpensive for expensive raw materials" and "reduced environmental impacts" were also significant sources of benefits in the *materials processing* cluster. "Better fits for customer end uses and processes" was a significant benefit in the new products cluster as were "more effective use of raw materials" and "substitution of inexpensive for expensive raw materials," jointly.

	Quality	Energy	Fit	Raw Mat'l &Substitute	Raw Mat'l &Environ	Substitute &Environ
Manufacturing (n=7)	4	3	1	1	0	0
High Technology (n=6)	5	0	0	1	0	0
Materials Processing (n=6)	4	1	0	0	1	3
New Products (n=3)	3	0	2	2	1	1

TABLE 7: ECONOMIC BENEFIT SOURCE BY CLUSTER (FREQUENCY)

Innovation Cluster Examples

Manufacturing cluster innovations can be characterized as process innovations originating with an *equipment maker* and having low compatibility for *end users*. Stated more simply, these appear to be *equipment maker* process innovations with occasional input from a *manufacturer* and no input from *end-users*. "Improved product quality" and "Reduced energy consumption" were most often claimed as economic benefits. A typical innovation in this cluster was the development of a continuous production line for LVL, featuring a continuous double belt press. According to Graf (1999), the source of this innovation was *equipment maker*, J. Dieffenbacker GmbH. The innovation results in higher quality and lower costs for laminated veneer lumber (LVL) manufacturers. The continuous LVL line is comprised of a veneer feeder line, a continuous lay-up station, a microwave pre-heater, a continuous press, a cross-cut saw, and a billet stacker. The line runs fully automatically with a hands-off handling system which minimizes human error and labor costs, and provides total control of the production parameters. Sources of economic benefits include reduced glue spread weights and low variability in final product properties.

High technology cluster innovations can be characterized as process innovations originating with an *equipment maker* and having high compatibility for the *equipment maker* and low compatibility for the *manufacturer* and *end-user*. Thus, the *equipment maker* is much more familiar with the new technology than the *manufacturer*. There appears to have been little or no participation by *manufacturers* or *end-users*. Typically, these innovations were new equipment for materials testing. "Improved product quality" predominated as the source of economic benefits. A typical innovation in this cluster was the development of an on-line stiffness tester by *equipment maker*, CAE Machinery Ltd.

As described by Lister (2000), the stiffness tester provides real-time bending stiffness data for every panel produced by a mill. This allows the effect of small changes in process parameters or raw material properties to be almost immediately known. As a result, the manufacturing process can be more accurately controlled, panel variability can be minimized, and average panel properties can be adjusted closer to minimum code requirements. Sources of economic benefits include reductions in raw material usage and lower panel costs. Also, manufacturers can promote their products as "100%" tested, thereby guaranteeing panel stiffness levels.

Materials processing cluster innovations can be characterized as process innovation originating with an *equipment maker* and having moderate compatibility for the *equipment maker* and *manufacturer* and low compatibility for the *end-user*. After "improved product quality," "substitution of inexpensive for expensive raw materials" and "reduced environmental impacts" were jointly claimed as sources of economic benefit. A typical innovation in this cluster was the development of two-stage or high power refining. According to Vajda (1994), Pepper (1994), and Lundgren (1994), the sources of the innovation were *manufacturers*, Fletcher Wood Panels Ltd., Canterbury, Panfibre, and Blue Ridge, and *equipment maker*, Sunds Defibrator AB. High power refining was first initiated in order to increase the output of the refining section. This increases throughput as well as fiber quality. Later, it was determined that the innovation permitted the use of small, low-cost wood residues in the manufacture of high-quality MDF.

Based on a very small number of cases, *new products* cluster innovations can be characterized as product innovation originating with an *equipment maker* or as combination product/process innovation. Compatibility was moderate for the *equipment maker*, *manufacturer*, and *end-user*. End-user technical capabilities appear to be more important than in other innovation clusters. After “improved product quality,” “better fits for customers,” and jointly “more effective use of raw materials” and “substitution of inexpensive for expensive raw materials” were claimed as the sources of economic benefit. In this cluster a typical innovation was the development of cement-bonded board products. According to Schwarz, Wentworth and Eilmus (1994) and Habighorst (1998), BISON (now Kvaerner Panel Systems) introduced this semi-dry system whose primary raw materials are wood waste, cement, and water. The process is capable of using a wide range of raw materials where cement and fibers or flake type lignocellulosic materials are the main components. Materials like fly ashes, amorphous silica components, silica sand, plastic, glass, and pulp fibers have been used. Economic benefits are derived from the ability to produce fire, termite, fungus, and weather resistant, durable products.

Conclusions

The selection of the *International Particleboard/Composite Materials Symposium Proceedings* as the sole data source has consequences for the interpretation of the results. The sample of 22 innovations represents a population of the types of innovation that would be submitted to and published in the *Proceedings*. The resulting bias is undefined, but the *Proceedings* are undoubtedly biased in favor of the interests of the intellectual community that it serves. Also, of note are “trade secrets” which would have prevented innovation descriptions from appearing in print even if they were of interest to the *Proceedings*’ community. That said, the authors believe that the findings suggest some general conclusions. First, particleboard and composite materials innovation has been dominated by process innovation by *equipment makers*. *Equipment makers* dominated every innovation cluster and introduced the new technologies appearing in the *high technology* cluster. Indeed, a number of equipment maker innovators were involving themselves in the production of particleboard and/or composite materials for the first time. Perhaps as important, particleboard and composite materials manufacturers were not the sources of *high technology* innovation. Second, the involvement of *manufacturers* was greatest in the *materials processing* and *new products* innovations, and *end-users* were most involved in *new products* innovation. Finally, economic benefits from “improved product quality” predominated.

The findings also seem consistent with the “transitional” phase in the Utterback-Abernathy model of innovation dynamics. Utterback suggested that for non-assembled products “the rate of process innovation quickly outstrips the rate of product innovation,” and “process innovation dominates the industry as it passes through the transitional and into the specific phases of its evolution.” During the transitional phase, competitive emphasis is on producing products for more specific users, as the needs of those users become more clearly understood. Product and process innovations become more tightly linked. Materials become more specialized, and expensive specialized production equipment appears, often in the form of islands of automation. As Utterback also suggests, this probably represents a trend toward increasingly undifferentiated commodity-like products and greater capital intensity.

Speculatively applying Utterback’s concepts to the particleboard and composite materials industry, the authors suggest that for the foreseeable future most technology innovation is likely to take the form of improved automation, including better process control, and increasingly continuous processing in manufacturing. Competition between manufacturers will be on the basis of cost, although a few new products may be introduced which compete on the basis of performance or a combination of performance and cost. The authors expect most innovation to be driven by technology specialist *equipment makers* who, in some cases, may be new to the industry. This innovation will take the form of technology specialist equipment makers adapting their technologies to engineered wood production processes. Thus, *equipment makers* should be looking for new opportunities to apply their technologies to engineered wood manufacturing processes, and *manufacturers* should be looking for new equipment that might be beneficially applied to their production processes.

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