Sloan Management Studies

Report No. 00-2

Research Team:	Sanjay Chlabani (Research Assistant) Kathryn Curry (Research Assistant) Adriana Diaz-Triana (Research Assistant) Lisa Hunter (Research Assistant) John L. Maziarz (Research Assistant) Venkatakrishnan Peruvemba (Research Assistant) Diran Apelian (Advisor) John Bantham (Advisor) Kevin Celuch (Advisor) Jacqueline Isaacs (Advisor) Chickery Kasouf (Advisor)	
Focus Group:		
	David Au	(Quebec Metal Powders, Ltd.)
	Ralf Carlstrom	(Hoganas, NA)
	Paul Dusinberre	(Borg Warner Automotive)
	David Kasputis	(Hoeganaes Corporation)
	Steve Mashl	(Bodycote, IMT)
	David Schaeffer	(Cloyes Gear and Products)

Project 1: Buyer-Seller Relationships

Objectives

- Identify the factors that facilitate and inhibit the development of trust in buyer-seller relationships.

- Identify variables that distinguish between best and average relationships.

Strategy

Longitudinal interview based case studies of three P/M part producers and customers.

Concluding survey of P/M part producers to assess generalizability of the findings

Achievements Since April Meeting:

- Interviews concluded in one firm and continuing in two firms
- Paper accepted (pending revisions) by the *Journal of Business Research*

- Objectives for the next six months

- Conclude interviews in remaining firms.

- Develop a survey for Spring 2001 distribution
-

(See Appendix A for the full report.)

Project 2: Cost / Quote Estimation

Project Goals

- § To develop a user-friendly technical cost model that provides estimates of manufacturing costs for various P/M components
- § To assist PMRC members in adopting these tools as aids in product development and strategic decision-making
- § To examine opportunities to reduce costs by investigating changes to i) process input parameters and ii) manufacturing management decisions
- § To identify the major cost drivers by quantifying the cost breakdowns of individual manufacturing process steps

Achievements During April 2000 — November 2000:

The *PowderEx* model was built to generate part costs, and the results presented at the 1999 Fall and 2000 Spring PMRC meetings. Several suggestions were made at the last meeting (as per the Spring 2000 focus group minutes) and have been incorporated into the latest version of the model. These suggestions map to the following changes.

- Secondary heat treatment operations such as i) austenitize, quench and temper, ii)°steam treatment, or iii) carburizing, and have been incorporated as options in the ***PowderEx*** model.
- Secondary machining operations including drilling, facing, and milling, and have been incorporated as options in the ***PowderEx*** model.
- Maintenance rates for each particular process step are still assumed to be a fixed percentage of the equipment costs, but as suggested, each piece of equipment, e.g., furnaces, presses, etc. have separate inputs to allow different maintenance rates.
- The cost of gases and energy in the sintering operation are now allocated as a fixed cost rather than a variable cost, since the sintering furnace rarely shuts down.

(See Appendix B for the full report.)

Several additional changes were also implemented:

- Energy usage calculations were refined for each process step.
- The user interface was changed to minimize error in the material input area of the model.

- Input powder compositions were included on an additional worksheet within the model for user reference.
- A new user tutorial was developed and included in the user manual to illustrate how to utilize the new additions to the model.
- The ***PowderEx*** user manual was updated to reflect these changes.

Several suggestions have not yet been implemented in the ***PowderEx*** model. These include:

- Issues of equipment dedication: the addition of the ability to select two different press lines with different utilization rates for manufacture of a given component is currently not included in the model.
- Issues of more complicated sensitivity analyses: the addition of the ability to automatically generate three-variable simultaneously sensitivity analyses for any component scenario has not been incorporated.

More detailed information on the changes is presented in each section below.

Heat Treatment Steps

As of the Spring 2000 PMRC meeting, heat treatment costs were only able to be included as outsourced costs. To improve the capabilities of the model, several heat treatment methods were added to the model. In addition to the option of outsourcing the parts, three in-house heat treatment options are now included. Currently, the user can select from i)˚austenitize, quench and temper, ii) steam treatment, or iii) carburizing. The model is designed to allow only one step to be selected, eliminating any user error. There are two places in the model where information is required. First the appropriate heat treatment step is selected under the *Process Steps* input area, which acts essentially as an on/off switch for inclusion of a heat treatment process step. Second, the specific information on the heat treatment process information needs to be entered (scrolling down the *Inputs* worksheet) under that specific heat treatment process step. See the revised User Manual (Version 1.0) for further information.

Machining Steps

Addition of machining steps to the model allows the user to implement a variety of features into the as-sintered part. If the user desires an additional feature be added to a component, there are three specific steps — drilling, facing, and milling — from which to select. Drilling can be used to incorporate additional holes required for mounting or alignment. Facing can be used to bring the as-sintered part to general dimensional or geometric tolerances that are unable to be obtained through the standard P/M processing. Milling can be used to incorporate any annular features, such as o-ring grooves, into the face of the component. The model is set up so that any or all of the above machining features can be incorporated into the component. There are two places in the model where information is required. First the appropriate machining steps are selected under the *Process Steps* input area, which acts essentially as an on/off switch for inclusion of a machining process step. Second, the specific information for each selected machining process needs to be entered (scrolling down the *Inputs* worksheet) under that specific process step. See the User Manual (Version 1.0) for further information.

Energy Usage Calculation Refinements

Originally, the ***PowderEx*** model calculated energy costs by using the motor nameplate power rating, and multiplying it by the process cycle time to obtain a billable energy cost. Upon further investigation, it was found that for all non-thermal process steps, the motors in the equipment typically never run at maximum power output. Therefore, a lower power rating should be used, depending on the load requirements. For example, the powder blender uses different amounts of power depending on the quantity of powder that is blended. Nominal equipment efficiencies were obtained and used in the model, based on information available from the National Electrical Manufacturers Association (NEMA) nameplates, maximum operating power for equipment and operating speed. To obtain the power rating at a particular load, the user can utilize the relation:

$$P = T\omega_{Ave}$$

where P is the power required of the load, T is the torque and ω_{Ave} is the average rotational speed.

Due to inefficiencies in the motor, more power is drawn from the line than is required. To obtain a more accurate energy cost, the power requirement is divided by the nominal efficiency.

For equipment in the machining step, an alternative method was used to calculate the energy required of the machine to remove a specific volume of material. Values[1] were used as the basis for calculating energy costs. The method of calculating energy usage in the machining step is:

$$E = R\left(\frac{V}{t}\right)$$

where E is the energy use in watts, R is the specific power requirement of the material in (W-s/mm^3), V is the volume of material to be removed from the part in mm^3, and t is the cycle time in seconds. The range of the power requirement *(R)* for machining steel is between 2.7 and 9.3°W-s/mm^3. In the ***PowderEx*** model, a value of 7 was used for R due to the higher stresses on the tool that arise from porosity in the material in the drill and milling step. For the grinding step, energy requirements are higher and therefore there is a significantly higher range of values. To calculate the energy costs, the energy (as calculated above) is multiplied by the cycle time and by the energy rate.

User Interface Improvements

Several improvements to the ***PowderEx*** input page were made regarding the powder inputs. In the previous version of ***PowderEx***, alloying elements were added using a macro, which had potential for error on user inputs. Hence, the macro was eliminated,

---

[1] Kalpakjian, Serope, *Manufacturing Engineering and Technology,* Addison Wesley, Reading, MA, 1989, p.594 and p. 760

and was replaced by combo-boxes for each individual element (graphite, nickel, copper, and Acrawax C). Each element is limited to its composition ranges for a typical nickel steel (0 - 1% for graphite, 0 - 8 % for nickel, 0 - 2.5 % for copper, and 0 - 1.5 % for Acrawax C). The compositions can be selected in 0.05% increments. As a final addition, a new sheet was incorporated to provide the user with a list of elemental compositions of all powders available to the user (e.g., Ancorsteels, Distalloys) as a readily available reference guide. This is useful for checking the alloying elements that are added to the blend.

User Manual/Tutorial

Due to these changes in the ***PowderEx*** model, the user manual and tutorial were updated. With the addition of the new process steps, the user tutorial now includes input information to reflect the additions of the heat treatment and machining steps. The case study for the tutorial involves a small FN-0200 gear, with an annular o-ring groove milled into one face of the gear, which is carburized in-house.

Publications

Several conference papers have been generated and presented from completion of Mehul Shah s Masters Thesis. These include:

1. J. A. Isaacs and M. N. Shah, *Economic Competitiveness of P/M Industry* , **Proceedings of Powder Metallurgy World Congress and Exhibition 2000**, Kyoto, Japan, November 12-16, 2000, The Japan Society of Powder and Powder Metallurgy and Japan Powder Metallurgy Association, Kyoto, Japan.
2. J. A. Isaacs and M. N. Shah, *Development of Technical Cost Models for P/M Processing of Non-Automotive Parts* , Invited, **Proceedings of APMI 2000 International Conference on Powder Metallurgy and Particulate Materials,** May 30 - June 3, 2000, New York NY, Association of Powder Metal Industries International, Princeton, NJ, CD-ROM.
3. M. N. Shah and J. A. Isaacs, *P/M Processing of Gear Components: Case Studies of Economic Competitiveness* , **Proceedings of APMI 2000 International Conference on Powder Metallurgy and Particulate Materials,** May 30 - June 3, 2000, New York NY, Association of Powder Metal Industries International, Princeton, NJ, CD-ROM.

Future Work

- Additional case studies should be run and the ***PowderEx*** model can be fine-tuned. This work is in progress through the competitive analysis study of several machined and P/M gears.
- Other secondary operations such as oil impregnation could be added.
- New P/M technologies, such as sinter hardening and warm compactions with DP/DS, could be investigated.
- Investigation could be initiated on whether addition of multivariate sensitivity analyses, i.e., changing the value of two or more variables at the same time, should appear as a graphic on the *Output* worksheet and whether a generalized format can be generated.

- More statistical analyses should be carried out for the @RISK results to create broader understanding. The level of confidence in the result is one such analysis that should be performed on the part cost.
-

Project 3: Managerial Assessment of Competitive Advantage

Objectives

- Identify managerial representations of competitive advantage in the PM parts industry, heat treating, and aluminum casting (thus, taking advantage of the research synergies allowed by the MPI consortia).

- Examine determinants of these representations.

- Examine the relationship of competitive advantage representations to information use.

Strategy

- Mail questionnaire of the P/M, metal casting and heat treating industries

Achievements Since April:

- Initial data analysis completed and results sent to respondents

- Additional data analysis completed and a paper was submitted to Industrial Marketing Management.

(See Appendix C for the full report)

Objectives for Next Six Months:

- Submit articles in IJPM and similar journals in casting and heat treating
- Assess possible extension of the study with overseas part producers

Project 4: The Impact of Ebusiness on P/M Part Producers

Objectives

- To assess the impact of ebusiness on P/M part producers

- To identify the factors that facilitate and inhibit ebusiness initiatives in P/M part producers

- To assess the impact of ebusiness strategies on buyer-seller relationships.

Strategy

- Initial questionnaire of the P/M industry with MPIF (including all official representatives) to assess the state of ebusiness in P/M

- A follow-up questionnaire merging the buyer-seller study with ebusiness. The combined study will address the impact of ebusiness on buyer-seller relationships in the supply chain

Progress Since April:

- Data collection during the summer with MPIF. The email/fax questionnaire generated 40 responses. Preliminary data analysis has been completed and will be presented at the November meeting. We found that most P/M web use is promotional. Few companies currently execute electronic transactions, and the average estimate of electronic sales in two years is 19.1% of total sales. Scheduling and customer service are the ebusiness applications expected to have the greatest increases in importance within the next two years.

Objectives for the Next Six Months:

Design a follow-up questionnaire integrating key issues from the buyer-seller relationship project with for spring 2001 circulation.

Sloan Management Studies

New Project, NU Research Team: Jacqueline A. Isaacs (Advisor)
Adriana Diaz-Triana (Research Assistant)

Project 5 (new): Eco-Environmental Assessment of P/M Industries

Project Goals

As a benefit from this ambitious project, the participants from the P/M industry will be able to demonstrate that companies in this sector are environmental leaders, by pledging cleaner operations through the reduction of hazardous emissions, and therefore reduction of worker and community exposure. The output from TCMs can help to explore financial savings by becoming aware of opportunities for pollution reduction, resource conservation, and cost reduction of unnecessary reporting, permitting and monitoring. Results from this study will help to elucidate the effect of alternative manufacturing practices that improve environmental performance on the resulting manufacturing costs.

§ To determine a set of baseline of emissions from the US powder producers and US˚part producers, and to analyze the trends over a five-year period.
§ To identify technical options to reduce wastes and emissions in P/M manufacturing.
§ To identify costs associated with environmental reporting and permitting, as well as with cost reduction opportunities in management practices that result from changes in manufacturing.
§ To identify incentives that would promote emission reductions, yet maintain viable manufacturing economics.
§ To develop tools to assess alternative pollution reduction strategies (e.g., source reduction).

- To develop an add-on spreadsheets to the ***PowderEx*** technical cost model that provide estimates on alternative manufacturing costs for various pollution abatement equipment, with a focus on minimization of solid wastes and air emissions.

Achievements During April 2000 — November 2000:

This project began in June 2000, as a Ph.D. thesis project. This work is currently sponsored by a NSF Career Award, entitled Integration of Environmental and Economic Assessment of Advanced Materials Manufacturing . Thus far, we have explored several public databases for information on emissions for US companies in both powder production and P/M part production. Trends for a five-year period (1993 — 1998) were investigated. Results and a full discussion of the techniques used to gather and assess the trends are discussed in the draft manuscript (included in this report), entitled Environmental Trends for the U.S. Powder Metallurgy Industry .

(See Appendix D for the full report.)

Future Work

The bullets above and the draft manuscript discuss the current focus and directions for our future work.

A PERSPECTIVE OF PARTNERSHIPS BASED ON INTERDEPENDENCE AND DIALECTICAL THEORY

John H. Bantham
Illinois State University

Kevin G. Celuch
Illinois State University

Chickery J. Kasouf
Worcester Polytechnic Institute

Corresponding Author:
John H. Bantham
College of Business
Department of Management and Quantitative Methods
304 Williams Hall
Campus Box 5580
Normal, IL 61790-5580
Phone: (309) 438-7263
Fax: (309) 438-5510
e-mail: jhbanth@ilstu.edu

Abstract

Business partnerships can serve as a significant source of competitive advantage. The present paper extends the business relationship literature by melding interdependence and dialectical theory from the marriage literature with extant buyer-seller partnership concepts in the development of a framework that contributes further insight to understanding interorganizational relationships. We examine the viability of borrowing conceptions from a nonbusiness domain through qualitative field interviews with relationship participants representing multiple functions on both sides of partnership dyads. This work holds important implications for future exploration and management of buyer-seller partnerships.

A PERSPECTIVE OF PARTNERSHIPS BASED ON INTERDEPENDENCE AND DIALECTICAL THEORY

Introduction

Few businesses are independent, self-sufficient organizations. Rather, they are part of an integrated system of upstream suppliers and downstream customers that produce and distribute products and services. Most companies are intermediaries in this chain, receiving inputs such as materials, components, and services from upstream supplier companies, performing some transformation process with these inputs, and selling the resulting products or services to downstream customer companies. The process continues along the chain, which eventually terminates with the end-user. This is the concept behind what is known as the value-added chain (Johnston and Lawrence, 1988), the customer value chain (Ashkenas, 1990), or what is most often simply referred to as the supply chain.

The purpose of the supply chain is to maximize profit for the chain by producing higher value products or services for the end user than the competition does. Historically, most firms have viewed their role in this supply chain from an independent perspective, seeking to maximize their own profitability in the short run, sometimes even at the expense of its customers and suppliers. This perspective, however, is valid only if transactions between buyers and suppliers are discrete *market-based exchanges* (Williamson, 1985). This perspective fits what Webster (1992) calls the *traditional microeconomic profit-maximization paradigm,* which he describes as follows:

> . . . the firm engages in market transactions as necessary to secure the resources (labor, capital, raw material, etc.) it requires for the production of the goods and services it sells in the competitive marketplace. Each transaction is essentially

> independent of all other transactions, guided solely by the price mechanism of the free, competitive market as the firm seeks to buy at the lowest available price (p. 5).

While the paradigm described above might still be appropriate for pure market transactions, this type of transaction is rare in today s marketplace. Most transactions are part of an ongoing relationship between buyer and supplier (Webster, 1992). Firms that have embraced this paradigm in the face of today's competitive forces have unintentionally put themselves at a competitive disadvantage relative to firms that recognize their interdependence with other members of their supply chain (Ashkenas, 1990). Indeed, the ability to establish collaborative relationships across organizational boundaries can be a source of competitive advantage (Liedtka, 1996).

The perspective of the supply chain as a more interdependent system of firms has led to the development of more collaborative, partner-like relationships between buying and supplying firms. These relationships have been the focus of an expanding body of academic and practitioner literature in both the operations and marketing streams of literature, which have explored the following aspects:

- The characteristics that differentiate partnerships from traditional buyer-seller relationships (Ashkenas, 1990; Fontenot and Wilson, 1997; Johnston and Lawrence, 1988; Landeros and Monczka, 1989; Leavy, 1994).
- The potential benefits and risks of partnerships (Lyons, Krachenberg, and Henke Jr., 1990; Newman, 1989; Spekman, 1988a).
- Guidelines for deciding when to use partnerships (Ellram, 1991c; Heide and John, 1990).
- The criteria used for selecting potential partners (Ellram, 1990; Spekman, 1988b; Stralkowski, Klemm, and Billion, 1988).
- The life-cycle stages of partnerships (Ellram, 1991a; Wilson, 1995).
- Guidelines for developing and implementing partnerships (Ellram, 1991b).

- The characteristics of partnership success and the obstacles that impede success (Anderson and Narus, 1990; Bantham, 1998; Dumond, 1994; Dwyer, Schurr, and Oh, 1987; Ellram, 1995; Mohr and Spekman, 1994; Morgan and Hunt, 1994; Paun, 1997; Pilling and Zhang, 1992; Wilson and Vlosky, 1997).
- The processes that partnerships use in problem resolution (Landeros, Reck, and Plank, 1995).

The above list (by no means meant to be all inclusive) attests to the growing body of literature related to business relationships. While calls for further research related to business relationships appear warranted, a growing body of unconnected research will not provide researchers and practitioners with sufficient direction to explore the development of more effective collaborative partnerships. What is needed is more theoretical "grounding" to aid the development of coherent bodies of research which ultimately offer pragmatic guidance to efforts aimed at enhancing business relationships.

The purpose of this paper is to offer a perspective that melds theoretical work in the interdependence and dialectical interpersonal relationship literature with extant buyer-seller relationship literature as a means of developing a framework that contributes further insight to understanding ongoing business relationships. One theoretical trail we believe to be worthy of further exploration involves the marriage metaphor.

The marriage metaphor holds a prominent place in competitive advantage literature (Hunt and Menon, 1995). For example, Dwyer, Schurr, and Oh (1987) and Hunt and Morgan (1994) incorporate aspects of marital theory in delineating issues related to initiating, developing, and maintaining buyer-seller relationships. Hunt and Menon (1995) note the appropriateness of the marital metaphor in capturing dyadic process dynamics. However, these authors also note the potential for expanding the metaphoric transfer (i.e., the borrowing of theoretical structures) of marital/personal relationships to buyer-seller relations.

Two theoretical orientations in the marriage/personal relationship literature include interdependence and dialectical theory. Briefly, interdependence theory establishes satisfaction and dependence as important concepts in social relationships (Rusbult and Buunk, 1993). Note foundational concepts of interdependence theory have been incorporated into extant frameworks of interorganizational relationships (e.g., Anderson and Narus, 1990; Soni, Wilson, and O Keefe 1996). The investment model extension posits relationship satisfaction, investments, and perceived quality of relational alternatives as significant variables in the process through which individuals become committed to relationships (Rusbult and Buunk, 1993). The investment extension explicity addresses the relationship among commitment and its immediate antecedents and therefore is potentially important to enhancing our understanding of business relationships.

The second conceptual perspective, dialectical theory, posits interpersonal relationships as requiring constant adjustments to conflicting and interconnecting forces (Montgomery, 1993). Present partnership frameworks have implicitly recognized the need to address tensions and conflict in relationships (c.f., Dwyer, Schurr, and Oh, 1987; Mohr and Speckman, 1994; Wilson, 1995). Through an adoption of dialectical theory we explicitly place the management of oppositional forces at the core of business relationships. In sum, we believe the melding of investment and dialectical theory holds the potential for enhancing the generative capacity of the marital metaphor in the buyer-seller relationship arena. We now turn to a more detailed description of each perspective.

The Investment Extension of Interdependence Theory

Interdependence theory is concerned with how individuals in relationships influence each other and the nature of their interaction in obtaining valued outcomes (Kelley, 1979; Kelley and Thibaut, 1978; Thibaut and Kelley, 1959). Two important attributes of relationships relate to the level of satisfaction and the degree of dependence. Satisfaction includes the feelings associated with a relationship. These feelings derive from an evaluation of outcomes obtained from a relationship in comparison to a standard, that is, a level of expected outcomes (CL). In contrast to satisfaction, dependence level is based on the comparison level for alternatives (CL-alt), that is, the lowest level of outcomes a partner will accept given alternative possibilities. Thus, interdependence theory clearly allows for the independence of satisfaction and dependence in partnerships. For example, in partnerships where relationship outcomes are below CL but above CL-alt, satisfaction will be low but dependence will be high. In contrast, for partnerships where relationship outcomes exceed CL but do not meet CL-alt, satisfaction will be high but dependence low (Kelley 1979; Kelley and Thibaut, 1978; Thibaut and Kelley, 1959).

The investment model extends the interdependence perspective by explicitly integrating the concept of commitment (Rusbult and Buunk, 1993). Commitment represents a long-term orientation, including feelings of attachment to a partner and desire to maintain a relationship, for better or worse. (Rusbult and Buunk, 1993, p. 180) According to investment theory, the level of satisfaction with a relationship influences commitment. Following the interdependence perspective, satisfaction is viewed as deriving from valued outcomes obtained from a relationship compared to a level of expected outcomes (CL). The investment model further posits that feelings of commitment increase when relationship partners believe that they have poor quality alternatives to their relationships (Rusbult and Buunk, 1993).

In addition, investment theory suggests that satisfaction also depends on equity effects, that is, a comparison of one s own inputs and outcomes to those of your relationship partner. Thus, in this view, satisfaction in the relationship may be denigrated when an individual feels underbenefitted (due to frustration) as well as overbenefitted (due to guilt). Observed effects of equity perceptions on satisfaction with interpersonal relations, however, tend to be weaker than effects of outcomes (Cate et al., 1988).

The investment perspective posits a final antecedent to relationship commitment the investment of resources in the relationship. Investments may be tangible (monetary) and intangible (emotional) and serve to enhance commitment through increasing costs of relationship termination (Rusbult and Buunk, 1993). The three posited antecedents of commitment have received empirical support. Satisfaction and investments have been found to positively relate to commitment and perceived quality of alternatives has been found to negatively relate to commitment. The tying of these three factors to commitment through the investment framework helps explain why individuals in unsatisfying relationships remain strongly committed due to a combination of poor alternatives and high investments (Rusbult and Buunk, 1993).

Dialectical Perspectives

As noted by Montgomery (1992; 1993), dialectics can refer to formal reasoning, social and political analysis, as well as the nature of social interaction. It is work in the latter domain that is relevant given the orientation of this paper. Consistent with the dialectical perspective of this domain, is the idea that oppositional forces are inherent in all social relations. Oppositions are defined in terms of relational forces that are interdependent and mutually negating. For example, the need for self-protection balanced against accessibility demands in relationships. Or, desires for a special, unique relationship opposed to social conformity pressures. Thus, in this view, relationships are ultimately defined in terms of the playing out of tensions with one polarity dominating at a particular point in time. These tensions may be consciously recognized or they may operate beyond individuals awareness. As a matter of course, tensions may be adapted to or actively managed but never eliminated (Montgomery, 1993).

Another foundational idea associated with dialectical social perspectives is that change is a result of reactions to opposing forces (Montgomery, 1993). In this view, constant change is conceived as an inherent dynamic of all relationships as partners oscillate between polarities over time. Further, connectedness and context characterize dialectical views of relationships (Montgomery, 1993). Closely paralleling systems frameworks (c.f. Bertalanffy, 1968), dialectics focus on relational forces in context rather than on discrete, elementalistic, individual-level aspects of relationships

An Organizational Partnership Framework

Based on investment and dialectical theory in the marriage/interpersonal relationship literature and prior business relationship literature, Figure 1 posits relationships among several variables relevant to the exploration of partnership dynamics. We suggest that mindset as well as skillset components serve as critical enablers in relationships. Liedtka (1996), based on a comparison of high performing and struggling professional partnerships, conceptualized effective partnering as consisting of mindset and skillset facets. The mindset facet included viewing partnerships as opportunities, a sense of at-stakedness, trust, and a readiness to learn from each other. The skillset dimension consisted of shared goals and realistic expectations, using conflict productively, and systems redesign. While we applaud Liedtka s use of field interviews as the basis for her components, we must note the lack of conceptal connectedness to prior theoretically relevant frameworks as well as a lack of conceptual clarity (e.g., trust as a dimension of the mindset construct; expectations as a facet of the skillset factor). Thus, we adopt her mindset and skillset labels only and reorient them in terms of dialectic and interdependence perspectives.

See Figure 1 on page 24.

In our view, the mindset enabler is a cognitive domain that encompasses awareness of dialectical relational tensions that are inherent in relationships as well as willingness to address these opposing forces. As noted earlier, opposing forces can consist of tensions endogenous and exogenous (contextual) to the relationship. Recall that from a dialectical perspective, relational forces are always present and operative. Key issues within this view relate to the degree of consciousness and the willingness of partners to actively manage the oppositions over time.

This dialectical perspective of a mindset enabler makes explicit an inherent theme in the business relationship literature (e.g., business relational exchange perspectives implicitly recognize dialectical dynamics as the need for partner adjustments, willingness to balance benefits and burdens and individual and shared goals over time, and partner ability to take the other s perspective and reconcile differences) (Dwyer, Schurr, and Oh, 1987; Mohr and Speckman, 1994; Wilson, 1995). In addition, the mindset enabler extends the significance of awareness in moving beyond a conception of awareness as a stage (cf. Dwyer, Schurr, and Oh, 1987) to viewing awareness as a continuing mindfulness of evolving oppositional tensions throughout a relationship.

Complementary to the mindset dimension is the skillset domain. We conceive of this enabler as connative in nature consisting of several communication behaviors that facilitate the management of dialectical tensions. Communication has been conceived as a cornerstone of a good marriage in the interpersonal relations literature (Fowers, 1998). Further, this variable domain is quite consistent with foundational interdependence perspectives which accord communication and behavior prominence in interactions between relational partners (Thibaut and Kelley, 1959). Communication skills typically addressed in counseling aimed at improving interpersonal relationships include: nondefensive listening, focusing attention on what a partner is saying rather than being preoccupied with future responses; active listening, including nonverbal encouragers as well as accurate summarizing of partner communication; self-disclosure, the sharing of needs, feelings, and specific requests; and editing, given that partners in conflict will often attend to negative behavior and engage in negative nonverbal and verbal exchange, sensitivity regarding self-censoring of attentional and communication responses can break negativity spirals so often associated with partner conflict (Fowers, 1998; Bussod and Jacobson, 1983).

Several business relational frameworks accord communication prominence in setting the stage for partnership development or as a significant variable in working partnerships (Dwyer, Schurr, and Oh, 1987; Anderson and Narus, 1990; Morgan and Hunt, 1994; Mohr and Spekman, 1994; Wilson, 1995). While, Anderson and Narus (1990) define communication in terms of the efficacy of information exchange, we extend prior organizational perspectives through the specification of behaviors that directly influence the efficacy of relational communication.

As indicated in Figure 1, we posit that the mindset enabler - awareness of dialectical relational tensions as well as willingness to address these opposing forces to be positively related to the skillset enabler communication behavior. Thus, we view the validation of alternative perspectives, and the openness to risk associated with awareness of and willingness to accommodate relational dialectical tensions to be antecedents of nondefensive and active listening, self-disclosure, and editing skills.

The present model proposes mindset and skillset enablers as antecedents to interdependent problem solving, conceived here as a key driver of relationships. Adapting characterizations of working relations from the marital relationship literature, interdependent problem solving can be viewed as consisting of: mutual understanding; a transference from individual to joint motivation; coordination of activities; and or joint outcome dependence (Fowers, 1998; Rusbult and Buunk, 1993; Bussod and Jacobson, 1983). Further, the marital relations literature has linked issues related to cognitive processing and behavioral execution to aspects of effective problem solving (Fowers, 1998; Bussod and Jacobson, 1983). Therefore we propose that mindset and skillset enablers will be positively related to interdependent problem solving.

Note that extant business relational frameworks include concepts such as expectations, mutual goals, conflict resolution, joint problem solving, and cooperation (Dwyer, Schurr, and Oh, 1987; Anderson and Narus, 1990; Morgan and Hunt, 1994; Mohr and Spekman, 1994; Wilson, 1995). Consistent with a dialectical orientation and the need for constant adjustment in relations, the present framework conceives of interdependent problem solving as a necessary process throughout working partnerships. Clearly, the specific issues addressed and activities performed will vary depending on timing and context issues. For example, at one point in a relationship, mindset and skillset enablers will facilitate interdependent problem solving related to mutual goal development. At another point in time, the enablers will serve to enhance the coordination of activities.

As depicted in Figure 1, interdependent problem solving, in turn, is viewed as a driver of two of the antecedents of relationship commitment. Note that we directly incorporate variables included in the investment extension of interdependence theory (Rusbult and Buunk, 1993). More specifically, problem solving is conceived as mediating the influence of mindset and skillset enablers on relationship satisfaction and relationship investments.

Problem solving is implicated in satisfaction given that individuals compare actual outcomes obtained from relational problem solving to expected comparison outcomes, with satisfaction associated with actual and expected outcome matches . Expected outcomes may be derived from intermediate problem solving efforts and/or previous relational experience. Consistent with investment theory, satisfaction will also be influenced through a comparison of one s problem solving inputs/outputs to those of a partner. Overall, satisfaction is enhanced when partner input/output ratios are perceived to be equivalent.

Problem solving is also implicated in the investment of relational resources.   That is, during the course of problem solving, individuals may become bound to the relationship in tangible and intangible ways. As noted earlier, investments may be tangible in form, as in the case of direct financial investments. Investments may also be intangible in nature, as in the case of social bonding between partners and the development of trust. Following from investment theory, increasing investments serve to intensify commitment given they increase the costs associated with relationship termination.

Note that we do not implicate problem solving in the final antecedent of relationship commitment — the perceived quality of relationship alternatives. The availability of partners is clearly related to timing and situational contexts. Additionally, consistent with interdependence theory, we view the evaluation of potential alternate partners as distinct from the evaluation of the current partner.

In sum, interdependent problem solving is viewed as positively related to relationship satisfaction and relationship investments. In turn, consistent with investment theory, relationship satisfaction and relationship investments are viewed as positively related to relationship commitment and the perceived quality of relational alternatives is viewed as negatively related to commitment.

While relationship satisfaction, relationship investments, the perceived quality of relational alternatives, trust, and commitment are prominently represented in the business relationship literature, conceived relationships among these constructs are less clear (Dwyer, Schurr, and Oh, 1987; Anderson and Narus, 1990; Morgan and Hunt, 1994; Mohr and Spekman, 1994; Wilson, 1995). Note that the melding of dialectical and investment theory from the marriage relations literature allows for an integration of these concepts with satisfaction and related equity perceptions, investments (including trust), and the perceived quality of relational alternatives as antecedents of relationship commitment.

Lastly, owing to the explicit adoption of dialectics, we conceive of ongoing organizational relationships as consisting of multiple, iterative feedback loops. Thus, driver feedback may reinforce or alter mindset and skillset enablers. Further, as implied in the discussion related to problem solving, related outcomes (i.e., satisfaction and/or investments) may also influence the mindset and skillset enablers. Finally, the level of commitment resulting from problem solving outcomes may influence mindset and skillset enablers.

Field Interviews

The purpose of these interviews was to serve as a check on the viability of the metaphoric transfer from the marriage/interpersonal relationship literature to buyer-seller relations and the development of the relationship model presented here. We believe this approach is an appropriate next step given the conceptualization of buyer-supplier partnerships as complex, dynamic entities.

Within each organization, multiple business functions interact both intra- and inter-organizationally, executing normal business transactions, designing and improving products and processes, jointly solving problems, and planning for the future. As our model contends, the two dyad entities and the functions within those units are dialectically interdependent. Yet, relatively few studies have looked at partnerships from the perspective of the matched buyer-supplier dyads (Ellram, 1995; Ellram and Hendrick, 1995). Those studies that have explored both sides of the partnership have done so from the single perspective of purchasing (representing the buyer) and sales/marketing (representing the supplier). Few studies have looked at partnerships from the perspective of those functions, other than purchasing and sales/marketing, that interact in the normal course of accomplishing everyday transactions between buyers and suppliers for example, engineering, quality control, and customer service. This study begins to address this gap in the current literature by using a multi-case study research design to explore buyer-supplier partnerships from cross-functional perspectives within both partnering organizations.

The present study employs a qualitative research methodology as described by Eisenhardt (1989), Miles and Huberman (1994), and Yin (1994). This methodology focuses on developing a deep, rich, understanding of the dynamics present within settings. The primary unit of analysis for the study is the partnership, focusing on the individual participants perceptions of the relationship. Previous research has shown that buyer-supplier partnerships exist in a number of different U.S. industries in both the manufacturing and service sectors. The literature has also shown that partnerships are more frequently associated with made-to-order items and direct operating materials (Ellram, 1995). This situation would favor firms in the manufacturing sector as being good candidates for studying on-going partnerships. The choice of manufacturing firms is further supported by the fact that most of the literature addressing partnerships has focused on the manufacturing sector (Ellram and Krause, 1994).

This study investigates five partnerships in the manufacturing sector. Qualitative evidence from the study sites should provide initial empirical grounding for the proposed framework. The primary sources of data for this study are personal interviews conducted with those employees who are involved with the management and operation of the partnerships. Companies ranged in size from approximately 50 employees to several thousand employees. Informants represent various functions within the organizations. The key informants were identified in preliminary discussions with primary contacts at supplier firms. In total 25 interviews were conducted for the study.

Personal interviews were conducted with the appropriate individuals within each firm of the partnering dyad. Participants were not explicitly cued in terms of dialectical and interdependence specifics. The interview typically began with the researcher asking the participant What their firm brings to the relationship? Further topics related to what it is like working with the partner- positives and negatives, the nature of information use, satisfaction with the partnership, and likelihood of continuing with the relationship.

Most interviews were conducted on site and typically lasted 30 minutes. Interviews were audio taped and later transcribed; notes were also taken. Additional interviews were conducted over the telephone and employed audio tapes as well as notes. The data gathered from the transcriptions of the interviews were used to create a case study database which was reviewed in light of the present framework.

Overall, dialectical tensions appeared to loom large in the relationships examined in this study. Informants representing top management, sales, engineering, customer service, and purchasing, on both the supplier and buyer side, made reference to having to reconcile such oppositions as: growth — risk, strong control — weak control, predictability — flexibility, cost — quality, top management perspectives — process employee perspectives , new workers — experienced/senior workers, and sharing information — withholding information. Consistent with dialectics, tensions existed in all relationship phases and tended to ebb and flow at various times and in response to various partner actions. In all cases, a reconciliation of opposing forces would positively influence the relationship, at least temporarily, while a failure to reconcile oppositions would negatively valence the partnership. The prevalence of comments related to the need for continuous give and take and settling on a middle ground would seem to support the potential significance of a dialectical conceptualization of interdependent relationships.

Recall in our framework, we posit the significance of two enablers mindset and skillset that we view as key facilitators of interdependent problem solving. Clearly, an awareness of and willingness to address the opposing forces cited above would enhance partners' working relationship. Informant phrases such as spirit of partnership , positive attitude , and willingness to jump through hoops characterize the positive side of the mindset enabler. One quote from an executive at a supplier firm exemplifies this mindset.

> If we wanted to stop shipping, we've got a huge of power. We'd be gone overnight though . . . . trying to exercise any power might be suicide. So there is really not a power . . . . you're just trying to cooperate with them.

Two quotes, one from a quality control manager for a supplier referring to a customer mindset, the other from a supplier engineer noting a customer mindset, characterize the negative side of this enabler.

> Sometimes their attitude is like, this is the requirement - just do it - no reason .I see a more heavier handed approach .more demanding, less willingness to negotiate .understand each others collective interests and then renegotiating a more realistic approach.
>
> Customers often design the ideal because they don t have applications experience. It is often difficult to get a customer to change .

The skillset enabler is conceived as consisting of communication behaviors that facilitate managing dialectical tensions. The following quotations, with corresponding parenthetical information regarding the informant and behavior, provide examples of the saliency of these behaviors.

> .they are willing to listen to our concerns and issues and take them back to their group .At (company) they listen .they listen to what you can or cannot do. They understand your problems (a supplier engineer referring to active listening of buyer).
>
> I think we need to listen, have good listeners. Once we truly understand what s going on then we need to go in that direction and deal with what we are hearing. Be very open to self-criticism and say we have a problem (supplier quality control manager describing the active, nondefensive listening required to improve the relationship with the buyer).
>
> Some negatives I guess is it seems to me that once the product gets out of the designers hand and goes into production it becomes more difficult. If we request changes they seem not to agree with us .the production engineer will say no this is the way it is (a supplier engineer referring to defensive listening/lack of editing of buyer engineer).
>
> We are responsive to customer requests and when they ask us to do something out of the norm I don t ever recall saying a flat out no without any negotiations or talking about it (supplier customer service representative referring to use of nondefensive listening/editing).
>
> Sometimes we get a little bit of emotion in there that escalates into an inappropriate position .(supplier quality control manager describing a failure to edit in communicating with a buyer).

> .I would say keeping them posted about what s going on. They expect to know from our end .if we are having a problem with something they expect to know about it if there is trouble (customer service representative describing the importance of disclosure in dealing with buyer).

Overall, informants provide a strong sense of the importance of mindset and skillset enablers as critical requirements for various facets of interdependent problem solving.

In the proposed framework, interdependent problem is viewed as the driver of business relationships. Recall it is conceived as the key consequence of the mindset and skillset enablers, which then, in turn, becomes the antecedent for significant relationship outcomes satisfaction and investments. Again we provide quotations with corresponding parenthetical information regarding the informant context.

> It s a cooperative effort. (Customer) tells us what they want and there are a lot of compromises along the way .Prints go back and forth five to six times (supplier marketing executive describing interdependent problem solving with buyer).
>
> .they jumped through hoops to get our product done and approved and continue to supply from that product on. They have tried to understand our needs and we have tried to understand theirs. They have worked with us for a long time and they have been very responsive and worked through their issues with us (buyer purchasing director describing interdependent problem solving with supplier).
>
> There is another important factor — engineering working together. Customers expect a lot of support from engineering. Also things have improved since they participated in costing. Their increased involvement in the costing process has helped build the relationship (supplier customer service representative discussing the importance of problem solving in relationships).
>
> I think we are good for each other. I think they push the envelope in some cases. We like the envelope to be pushed along with them. It kind of makes you think what s the next step and how far can you take this (supplier marketing manager describing the problem solving required for a challenging new part).

Overall, informants appeared to place problem solving that was interdependent in nature at the core of good working partnerships.

As noted previously, satisfaction and investments (including trust and social bonding) are significant outcomes of interdependent problem solving which affect relationship commitment. The following quotations with corresponding parenthetical information regarding the informant context provide examples of these concepts.

> I like working with (customer) so I would like to hold on to them. So much so that I don t mind that little extra to hold on to them (supplier customer service representative describing satisfaction with and related commitment to relationship with buyer).
>
> .basically the deselection process evolves from when you feel the relationship isn t mutually shared or when there is a situation where we are involved in an all give situation and no take (supplier sales manager describing the negative affect of perceived inequity on relationship satisfaction and commitment).
>
> We know a lot about each other, we have a trust there .I don t have to explain to them every step I take .I can just say trust me you will get them and it is done (supplier customer service representative describing trust in the relationship with buyer).
>
> It would be very difficult, not because we are economically tied in, but because we don t really want to break relationships. We have worked with people and became friends and allies in these relationships (supplier engineer describing the social bonding that would make it difficult to terminate the relationship with the buyer).
>
> There are a lot of bonds there, friendships, especially with the people from (customer). We have meetings, Christmas dinners, and go out for dinners. People at (customer) really look forward to that as it has developed over the years (supplier customer service representative describing social bonding in the relationship with buyer).

Not surprisingly, satisfaction appeared to play a strong role in partnership commitment. Somewhat surprising, however, was the exceptionally powerful impact intangible investments such as trust and social bonding seemed to exert on relationship commitment.

Overall, field interview data appear to offer initial support for concepts in the proposed framework. As such, these interviews serve as empirical grounding for the viability of the metaphoric transfer of dialectical interdependence from the marriage/interpersonal relationship literature to the business relationship domain.

Discussion

The present work contributes to the business relationship literature in several ways. First, we have extended extant theoretical perspectives through an expansion of the marital metaphor. Specifically, we have incorporated investment and dialectical theory from the marriage/ interpersonal relationships literature as a means of reframing, further developing, and integrating issues and concepts within the business relationships literature. The process has resulted in a proposed organizational partnership framework. Of note is the emphasis accorded mindset (awareness of and willingness to address dialectical tensions) and skillset (communication behaviors) enablers that move beyond constructs included in extant business relationship models. Further, their proposed connection to a key driver as well as the conceptualization of the driver as interdependent problem solving integrates several domains in existing models. Conceiving of problem solving as multidimensional and iterative in nature is in keeping with contemporary views of problem solving as well as employee experience of the phenomenon. So conceived, our framework implies that to understand relationship satisfaction, investments and commitment, one must understand the interaction among enablers and driver.

The present conceptual extension contributes to research in the area in multiple ways. While the model clearly requires additional empirical examination, this work represents a first look at buyer-supplier partnerships in terms of dialectical interdependence. To this end we have employed a qualitative research methodology incorporating matched buyer-supplier dyads as a means of exploring both sides of the partnership and have done so from multiple functions including top management, sales, purchasing, engineering, quality control, and customer service.

Given that the framework highlights required partner adaptation to oscillating polarities over time, further longitudinal qualitative explorations appear particularly warranted. Specifically, examining the process whereby intermediate outcomes associated with the resolution of tensions effect further interdependent problem solving would be a valuable contribution to the relationship literature.

The proposed framework also offers specific, testable propositions for quantitative investigation. Clearly the operationalization of constructs, particularly, the multidimensional problem solving concept requires attention. In terms of specific relations among concepts, the proposed role for interdependent problem solving as a mediator of the influence of mindset and skillset enablers on relationship satisfaction and investments begs exploration. Further, the identification of generalizable dialectical relationship tensions would also be particularly interesting. The interaction between the outcomes of interdependent problem solving, satisfaction and investments (including trust and social bonding) and perceived quality of alternatives in impacting commitment could prove fruitful. Lastly, the inclusion of other relevant variables for examination, where appropriate, could serve to add depth to the present framework. For example, how might attributional processes related to problem solving outcomes affect mindset and skillset enablers?

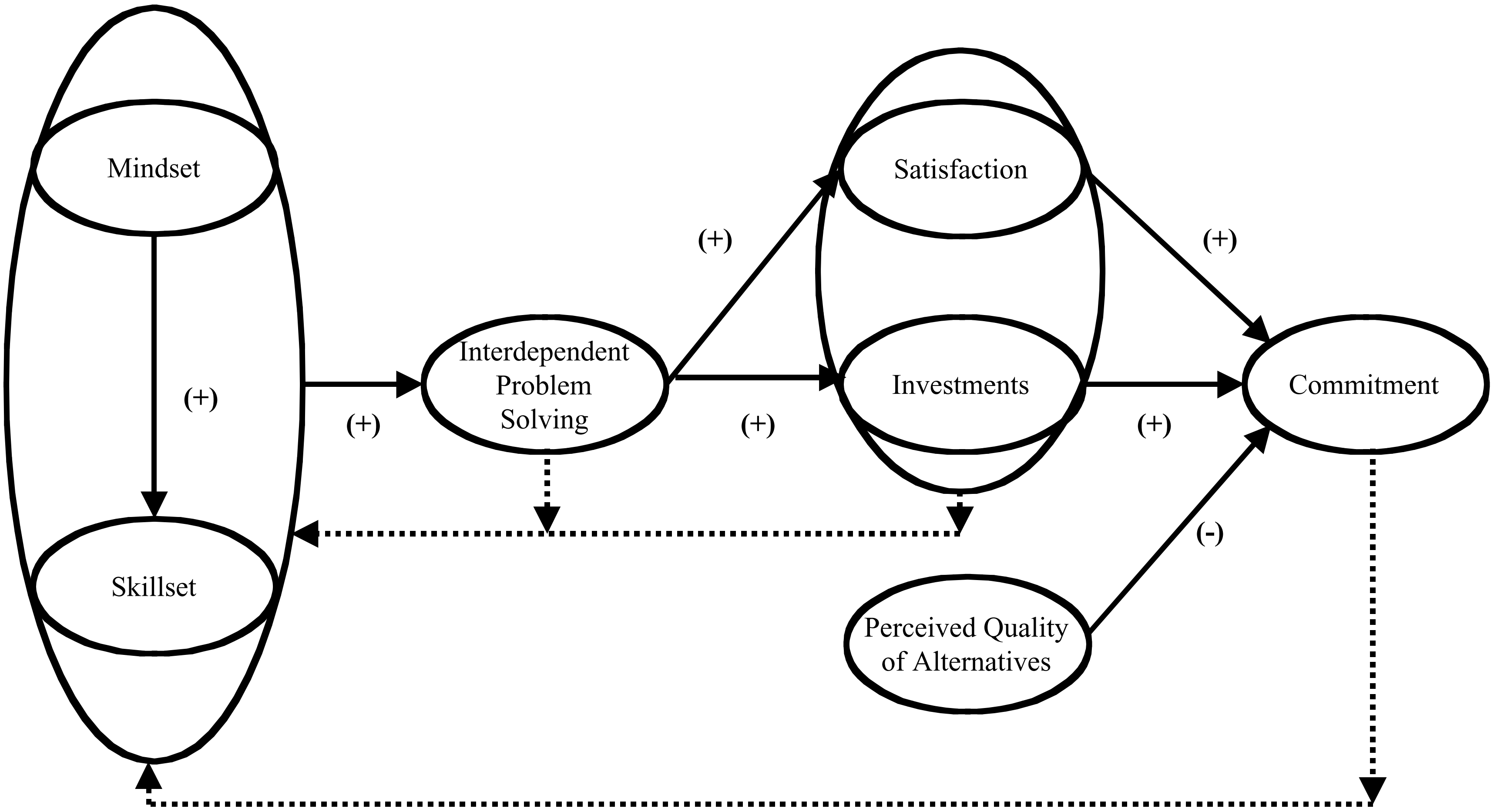
From a practitioner standpoint, the framework has important implications. First, the significance of perspective taking cannot be overemphasized as a means of addressing dialectical tensions. This observation was highlighted over and over by multiple informants in our field interviews. However, as our model posits, awareness of the need to see the other side is not enough to insure interdependent problem solving. A partner must also be willing to actively address — accommodate or manage the oppositions. Clearly, organizational rewards and supporting resources can help enhance motivation to partner.

Even with the adoption of a partnering mindset, the achievement of truly interdependent problem solving will prove elusive without the complementing skillset — communication behaviors. Thus, training that reinforces skills relating to active and nondefensive listening, disclosure, and editing provide specific tools that are critical for dealing with the continuous tensions encountered in various stages of problem solving. Informant responses unequivocally indicate than even when partners are aware of and somewhat willing to address an issue, it is the way they communicate about the issue, more so than the amount of communication, that can either facilitate of denigrate interdependent problem solving. Given the above, we concur with Bantham and Bobrowski (under review) who concluded that even in an increasingly electronic communication environment (i.e., characterized by heavy reliance on e-mail, fax, and shared databases), face-to-face communication is critical to partnership success.

In conclusion, understanding business partnerships will continue to be a significant topic within the business literature. It is our hope that this systematic examination of relevant theoretical constructs will contribute to future empirical efforts aimed at increasing understanding of working relationships in organizations.

Figure 1.

An Organizational Partnership Framework



PowderEx

P/M Part Processing Technical Cost Model

Version 1.0

User Manual

Northeastern University
MIME Department

November 2000

Developed with Funding from
the Powder Metallurgy Research Consortium
at Worcester Polytechnic Institute
and the National Science Foundation
Grant Number DMII-9734054

1. INTRODUCTION..**1**

A. PURPOSE OF MODEL 1
B. COST CLASSIFICATIONS..1
C. THE SCOPE OF COST MODELING 2
  Material Costs..*2*
  Labor Costs..*3*
  Energy Costs *3*
  Main Machine & Auxiliary Equipment Costs *3*
  Tooling Costs *3*
  Building Costs..*3*
  Maintenance Costs..*3*
  Manufacturing Overhead..*3*

2. LAYOUT OF POWDEREX **4**

2.1 INPUTS WORKSHEET..5
  A. Mixing / Blending Powder Input..*6*
  B. Molding..*6*
  C. Pre-Sintering & D. Sintering..*6*
  E. Repressing *7*
  F. Tumbling..*7*
  G. Machining *7*
  H. Heat Treatment..*7*
  I. Inspection Costs..*7*
2.2 OUTPUT WORKSHEET 7
2.3 MODEL WORKSHEET 9
  A. Mixing / Blending Powder Input..*10*
  B. Molding..*10*
  C. Pre-Sintering & D. Sintering..*11*
  E. Repressing *11*
  F. Tumbling..*12*
  G. Machining *12*
  H. Heat Treatment..*12*
  I. Inspection Costs..*12*

3. DEFINITION OF KEY INPUTS PARAMETERS..**13**

A. INPUTS WORKSHEET..13
  Product Life *13*
  Days per Year..*13*
  Electricity Cost..*13*
  Capital Recovery Rate *13*
  Equipment Life..*13*
  Building Unit Cost *13*
  Building Life..*13*
  Downtimes..*13*
  Auxiliary Equipment Cost *14*
  Scrap Rate..*14*

4. DESCRIPTION OF KEY OUTPUTS..**15**

A. COST BREAKDOWN & PIE CHART..15
B. IMPACT OF REJECT RATES ON COST PER PIECE 15
C. SENSITIVITY TO PRODUCTION VOLUME..15
D. EFFECT OF MOLDING CYCLE TIME ON PART COST..15
E. EFFECT OF ELECTRICITY COSTS ON PART COST 15

5. USER TUTORIAL..**16**

A. SENSITIVITY ANALYSIS 26

1. Introduction

This manual describes how ***PowderEx***, a technical cost model for conventional powder metallurgy (P/M) part production is used to generate part cost for specific input parameters. This document is meant to help the user get acquainted with the ***PowderEx*** model, developed at Northeastern University. The ***PowderEx*** model is built on a Microsoft Excel 97 spreadsheet and has macros built into it. When opening the spreadsheet, always open with “Enable Macros”, otherwise the model will not run properly. As the model and its accompanying files and macros require a lot of disk space, it is better to run the model from the hard drive.

To further understand the working of the cost model, users are recommended to read the manual while following along with a copy of the model open. It is advisable to RENAME a copy of the model as you work, so that the original version remains intact. A case study tutorial is presented in the last chapter for more detailed instruction.

A. Purpose of Model

The purpose of a Technical Cost Model (TCM) is to allow a user to calculate manufacturing costs for a product. In this case, the model is used to estimate manufacturing costs of any ferrous-based component fabricated via P/M processing.

The model incorporates any of the following processing scenarios:

- Single Press/ Sinter
- Single Press / Sinter / Repress
- Double Press/ Double Sinter
- Warm Compaction / Single Sinter

In addition to these primary operations, the following secondary operations are included:

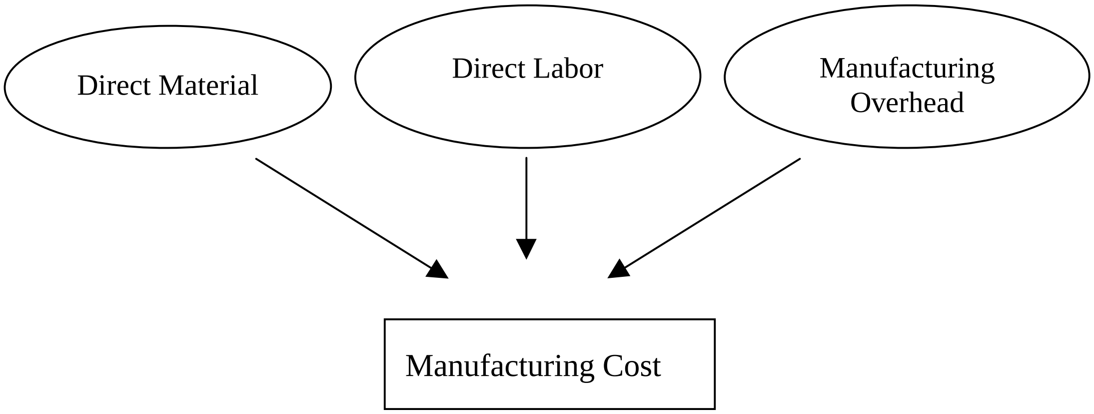
- Machining
- Heat Treatment
- Tumbling
- Final Inspection

B. Cost Classifications

Traditionally, the manufacturing cost or the COGS (Cost of Goods Sold) involves the following sub-costs:

- ✓ Direct Material
- ✓ Direct Labor

✓ Manufacturing Overhead



Direct Material is the raw material that is used to make the product and can be easily traced back to the product.

Direct Labor is the cost of wages, salaries, and benefits for the workforce directly associated with the production of the part.

Manufacturing Overhead includes all indirect expenses incurred by the company from the receipt of the production order until its completion, i.e., it being ready for shipment to the customer.

C. The Scope of Cost Modeling

The technical cost model aims to accurately estimate the manufacturing cost, which is composed of the following costs:

- Material Costs
- Labor Costs
- Energy Costs
- Main Machine & Auxiliary Equipment Costs
- Tooling Costs
- Building Costs
- Maintenance Costs

Material Costs

Material expenses include the costs of the iron powder, alloying additions and lubricants. It also includes the cost of gases used in the sintering furnace.

Labor Costs

Labor Costs are made up of wages for direct and indirect labor. These are a function of the wages paid, the total number of workers required to conduct the operations, and the time required to produce the part.

Energy Costs

Energy costs are usually estimated from the requirements of the manufacturing equipment and the time required to produce a unit of product. Although individual pieces of equipment are rarely metered, their maximum energy usage and nominal operating efficiency are often listed on the manufacturer's placard somewhere on the machine. The energy costs are calculated by dividing the power rating by the operating efficiency, and multiplying it by the amount of time the machine is in operation and by the cost of electricity.

Main Machine & Auxiliary Equipment Costs

The costs of the primary pieces of manufacturing equipment over the time period they are used for manufacturing the part in question are summed into Main Machine Costs. Depending on the manufacturing process, a great deal of auxiliary equipment, like handling systems might be required.

Tooling Costs

Tooling costs include the cost of first set of tools, subsequent sets and the cost of maintaining the tool sets.

Building Costs

This is cost to build or rent a production facility after the space requirements are determined.

Maintenance Costs

Maintenance costs are assumed to be a percentage of cost of capital equipment, tooling and building costs.

Manufacturing Overhead

The model predicts the direct material, direct labor and a large portion of manufacturing overheads. There are certain costs involved in the manufacturing overhead, which are difficult to estimate. These costs are very company specific and hence difficult to quantify. The following breakdown of manufacturing overhead is considered within the scope of the model:

Building Expenses including Rent, Insurance, Repairs, Heating and Lighting, Depreciation

Indirect Labor including Supervisors and Foreman, Machine Setters, Maintenance, Shop Clerk, Inspectors, etc.

The following overhead cost areas are considered outside the scope of the model:

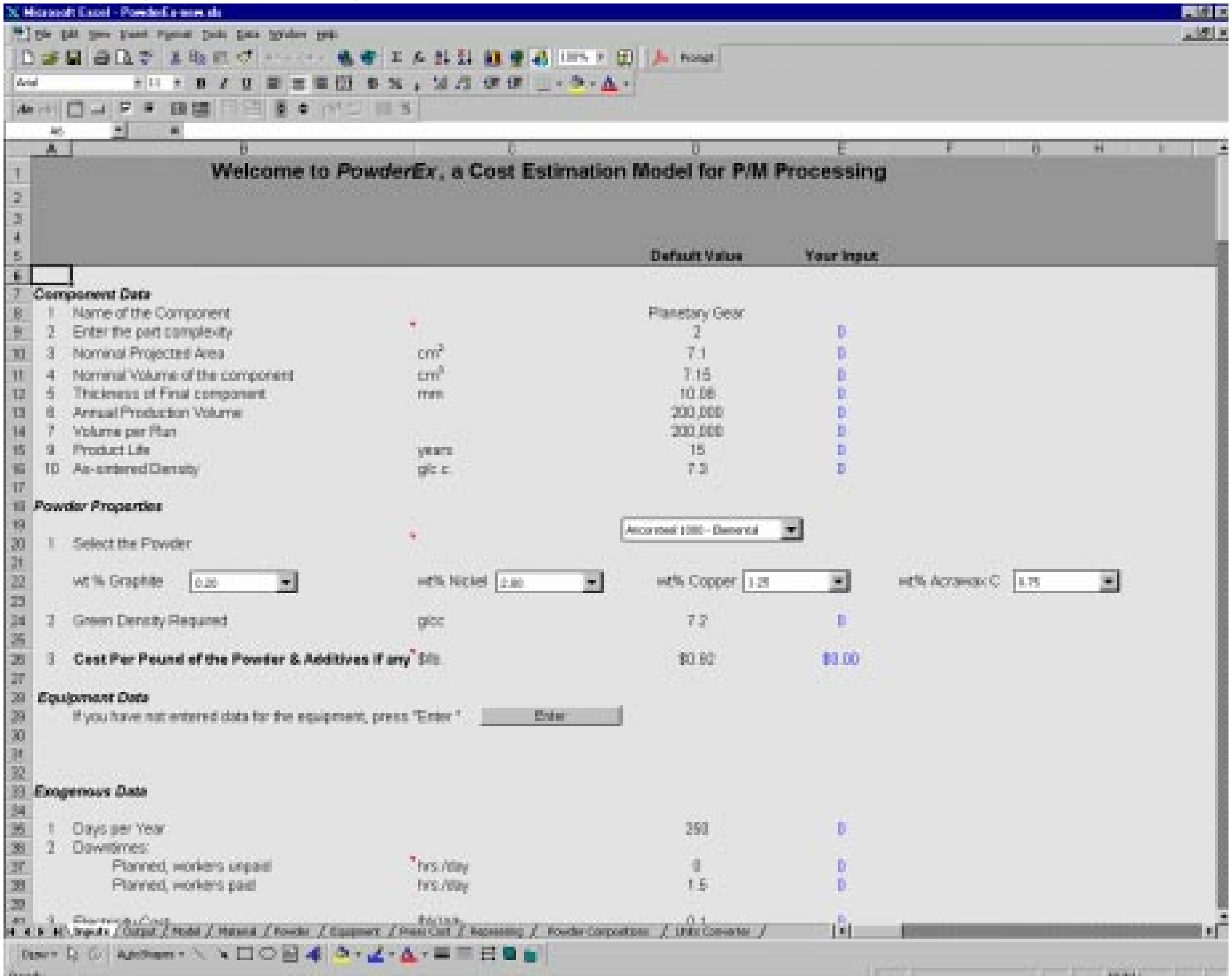
Service Departments including Quality Assurance, Purchasing, Maintenance, Receiving and Incoming Inspection, Material Control, Manufacturing Engineering, Cost Accounting

2. Layout of PowderEx

Upon opening the ***PowderEx*** model, the user finds that the model consists of ten different worksheets as shown by the different tabs in the screen print below:

- ***Inputs***
- ***Output***
- ***Model***
- ***Powder***
- ***Material***
- ***Equipment***
- ***Press Cost***
- ***Repressing***
- ***Powder Compositions***
- ***Units Converter***

(Change the zoom magnification to view this screen as shown on your own monitor.)



Welcome to *PowderEx*, a Cost Estimation Model for P/M Processing

			Default Value	Your Input
Component Data				
1	Name of the Component		Planetary Gear	
2	Enter the part complexity		2	0
3	Nominal Projected Area	cm^2	7.1	0
4	Nominal Volume of the component	cm^3	7.15	0
5	Thickness of Final component	mm	10.08	0
6	Annual Production Volume		200,000	0
7	Volume per Run		200,000	0
9	Product Life	years	15	0
10	As-sintered Density	g/c.c.	7.3	0
Powder Properties				
1	Select the Powder			
2	Green Density Required	g/cc	7.2	0
3	**Cost Per Pound of the Powder & Additives if any**	$/lb	$0.82	$0.00
Equipment Data				
	If you have not entered data for the equipment, press "Enter."			
Exogenous Data				
1	Days per Year		250	0
2	Downtimes:			
	Planned, workers unpaid	hrs./day	0	0
	Planned, workers paid	hrs./day	1.5	0

There are four essential parts to the cost model: the areas where users input information, the areas where other input information is stored, the areas where calculations are done, and the areas where the cost results are located. The ***Inputs*** worksheet is the main input area. The ***Inputs*** worksheet and the input information stored in five other worksheets (***Powder, Material, Equipment, Press Cost,*** and ***Repressing***) are used to make cost calculations in the ***Model*** worksheet. The ***Output*** worksheet shows the salient results from the ***Model*** worksheet.

2.1 Inputs Worksheet

The first sheet that a user sees on opening the model is the ***Inputs*** worksheet, where data on a specific part is entered. On this sheet, the user enters all information regarding the part geometry, process parameters, and management decisions. A cell that has blue type color indicates an input cell that can be changed by the user, whereas any type in black is either a cell for calculations or a label. No attempt should be made to change the black cells. There are four columns, which require explanation. The first two columns show the required input parameter and its expected units. The next column is entitled Default Value, where the model displays residual inputs or inputs that have been calculated from estimations in the model. The next column is entitled Your Input, shows zeros “0” where the user can override the number that the model calculated (i.e., the number in the Default Value column). In some cells in the spreadsheet, a small red triangle appears in the corner of the cell. This indicates that a helpful “comment” is connected to this cell. To see the comment, simply place the mouse over the red triangle until the comment pops up.

In scrolling down the ***Inputs*** worksheet, the first section lists the *Component Data*, where the user must enter the part specifications. The part projected area, volume and thickness are solicited from the user. The annual production volume, volume per run and the product life, i.e., the number of years for which a contract is given are noted. In the next section down this sheet, *Powder Properties*, a drop-down list enables the user to select a variety of admixed, diffusion alloyed or pre-alloyed ferrous based powder, based on powders available from Hoeganaes Corp. Information on the available powders and the alloying additions is listed in the ***Powder*** and ***Material*** worksheet, respectively. Combo-boxes below the main powder list allow the user to add typical alloying powders, such as graphite, nickel, copper, and lubricants (Acrawax C). A powder cost is then calculated by the model in the following way. Depending on the required green density, the model estimates the tonnage required to press the part in question. This tonnage estimation is made using the graphs of Green Density vs. Compaction pressure (tsi) for each powder, which can be viewed in the ***Powder*** worksheet. The compaction pressure (tsi) is multiplied by the projected area to get the compaction tonnage needed to press the part. Depending on the powder and alloying additions selected, the model computes the cost per pound of the mix. Appropriate vendors provided the quotes for powders, and the model has incorporated the cost advantage of buying a large lot. The user can override the calculated value, if he has leverage with the powder producers and can get a better deal. All of the powder inputs entered by the user can be viewed in ***Material*** worksheet.

The next section is entitled *Equipment Data*. Here the user can enter equipment costs for the facility. After clicking “enter” the user is prompted to add the number of mixers, presses, furnaces, etc. that are available in the manufacturing facility or that the user wishes to use for comparative purposes. The user can enter up to a maximum of 10 of each type of machine. After entering this information, the user is also prompted to go to the ***Equipment*** worksheet, where all of the equipment costs and power consumption for each of machine must be entered. Note that the user cannot simply type "Mixer 5" and enter the data. The model must first generate the equipment line by knowing that the facility has five possible mixers; only then can the data for each line of equipment be input.

After entering the equipment data, *Exogenous Data* must be entered. The model solicits information on the plant activity, energy costs, direct and indirect labor rates, maintenance rates, etc. The capital recovery rate refers to the return on capital investment. A drop down list allows the user to select whether the customer provides the tooling or not.

In the next section, the *Process Steps* must be switched on or off depending on the required operations. A drop down menu allows the user to select the primary production process, which is either Single Press/ Single Sinter; Single Press / Sinter / Repress; Double Press / Double Sinter; or Warm Compaction / Single Sinter. The user must click Ok after selecting the process steps to allow the model to reconfigure.

As the user continues to scroll down the ***Inputs*** worksheet, more specific information about each process step is required for each process step.

A. Mixing / Blending Powder Input

If the mixer is dedicated the whole year to mix the powder for the component in question, then select "yes" on the drop-down box. Most equipment will not be fully dedicated, however. On the basis of this decision, a percentage of the full cost of mixer is allocated to the component. A drop down list allows you to select a mixer, depending on the capacities that are entered on the Equipment worksheet. If changes are desired, go back to the ***Equipment*** worksheet to adapt the equipment input. Unplanned downtime is the unscheduled breakdown, which results in stoppage of work. (For a more specific definition of the term "unplanned downtime", see Chapter 3). Other inputs include information on the mixing time, workers per line, equipment space and the cost of statistical process control (SPC) gages used for testing powders.

B. Molding

The model is set up to estimate the tonnage needed to press the part using the part dimensions and powder characteristics. The model requires the user to select one of the presses from the drop down menu, which was entered in the ***Equipment*** worksheet. The tonnage estimation allows the user to get an approximation of the tonnage needed and hence select the appropriate press. The cycle time needed for the part in question is calculated and displayed as a default value, but the user can override it. Information such as material yield, set-up time, tool cost, tool life, cost of statistical process control (SPC) gages, etc. is required from the user.

C. Pre-Sintering & D. Sintering

The model requires information on the atmosphere used in both the pre-sintering and sintering steps. The user needs to input numbers on cycle time, belt speed, set-up time, workers per line, cost of various gases, etc. As was the case in molding, the user selects a particular furnace in the facility by selecting it from the drop-down menu. To select appropriate equipment, it is imperative to enter the information in ***Equipment*** worksheet.

E. Repressing

The model estimates the tonnage needed to repress the part and the approximate base cost for such a press. The model assumes the parts to be dial or auto-fed. Once the machine tonnage is determined, the worksheet ***Repressing*** has a graph, which has the tonnage on the Y-axis and the production rate (pcs/hr) on the X-axis, helps determine the production rate. Again this information can be over-ridden. Information on tooling costs and life, set-up time, workers per line, etc is needed.

F. Tumbling

This is a secondary operation, which can be switched on or off depending on the process steps. Information such as the cycle times, power consumption, tumbler life, machine capacity, material yield, etc, is required of the user.

G. Machining

Secondary machining operations give the user options of adding any common features that are necessary to meet specifications, yet are too costly to incorporate into die design. Current options include drilling additional mounting holes, facing the gear to meet geometric tolerances (e.g. parallelism), and milling annular rings. Equipment information including machinery cost, lifespan, and operating efficiency must be entered in the ***Equipment*** worksheet by the user. Other information such as tool life, tool costs, cycle times, and material yields must be entered in the ***Inputs*** worksheet by the user.

H. Heat Treatment

Secondary heat treatment operations give the user a variety of options in obtaining the desired material properties. In addition to outsourcing the process step, there are three additional options: i) austenitize, quench and temper, ii) steam treatment, and iii) carburizing. The user must provide information on furnace cost, batch size, cycle time, and other relevant information in the ***Inputs*** worksheet regarding specific processes.

I. Inspection Costs

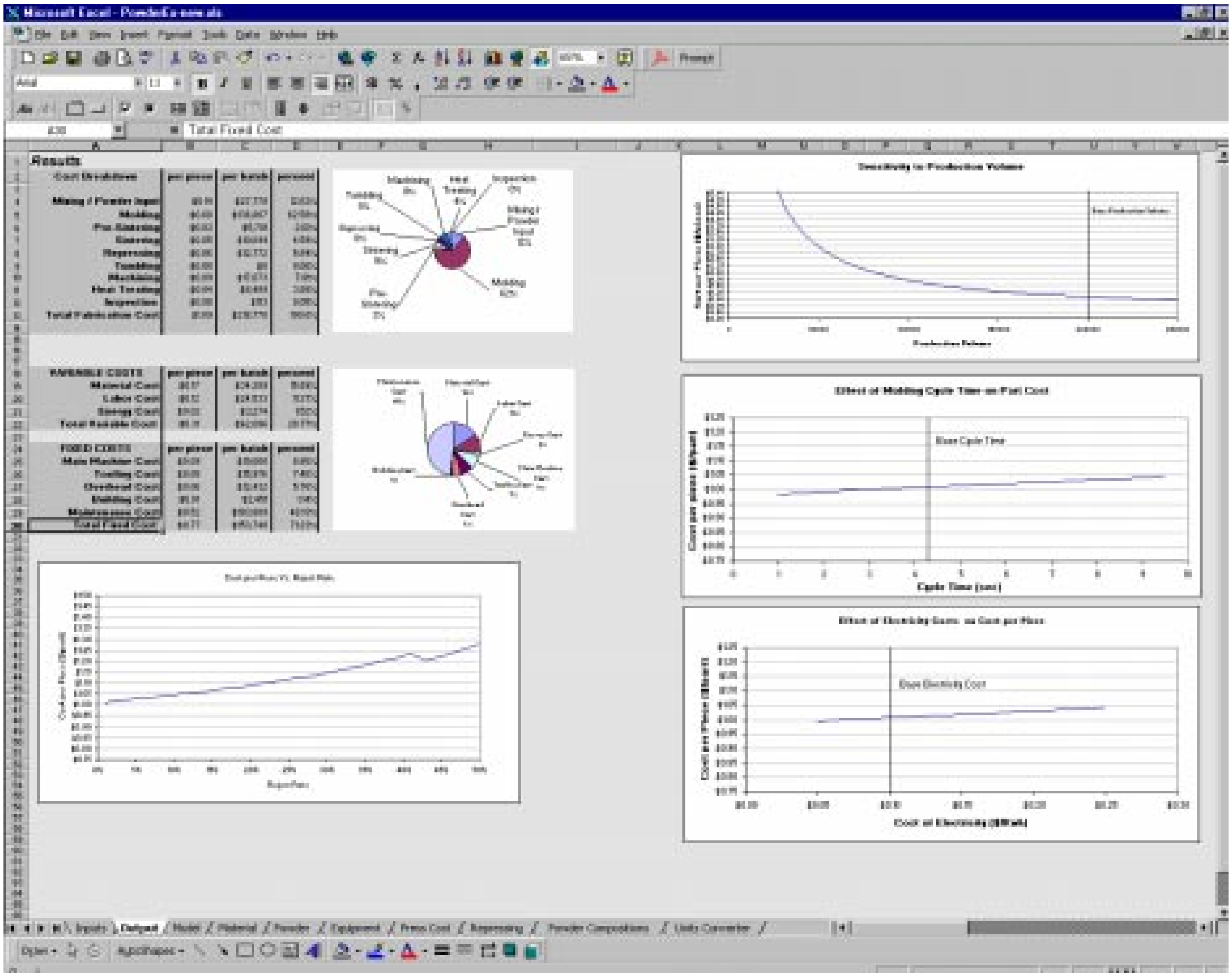
After all the processing is done, a small percentage of the lot is assumed to be inspected using a gear tester or some metrology equipment. This step is optional, as the P/M parts producer might be using the SPC systems and checking the parts as they come out of individual process steps. This steps solicits numbers on inputs such as the time to inspect a single part, reject rate, workers per line, metrology and testing equipment, cost of SPC system, etc.

2.2 Output Worksheet

Tabular and graphical results from the calculations in the ***Model*** worksheet are displayed in the ***Output*** worksheet. The results change as the input parameters in the ***Inputs*** worksheet are varied. The graphs in the ***Output*** worksheet show results from several of "What-if" manufacturing scenarios. The tables needed for these sensitivity analyses are located on the ***Model*** worksheet just to the right of the final cost summary table; it has a golden background. If sensitivity analysis needs to be done over a different range, it will be done automatically on entering the new data.

This worksheet is dynamic in nature, i.e., any changes made in the ***Inputs*** worksheet are reflected in the ***Model*** worksheet and are passed onto the ***Output*** worksheet. A sensitivity chart shows the variation in part cost as the production volume increases. Pie charts show the breakdown of processes or parameters that contribute to the final cost, and indicate opportunities for cost reduction. The next graph shows how the cost per piece varies as the reject rate changes. There is another graph, which shows the sensitivity of molding cycle time to part cost. These graphs help the user understand different costs, their effect on the final cost per piece, the critical inputs, and the major cost burdens.

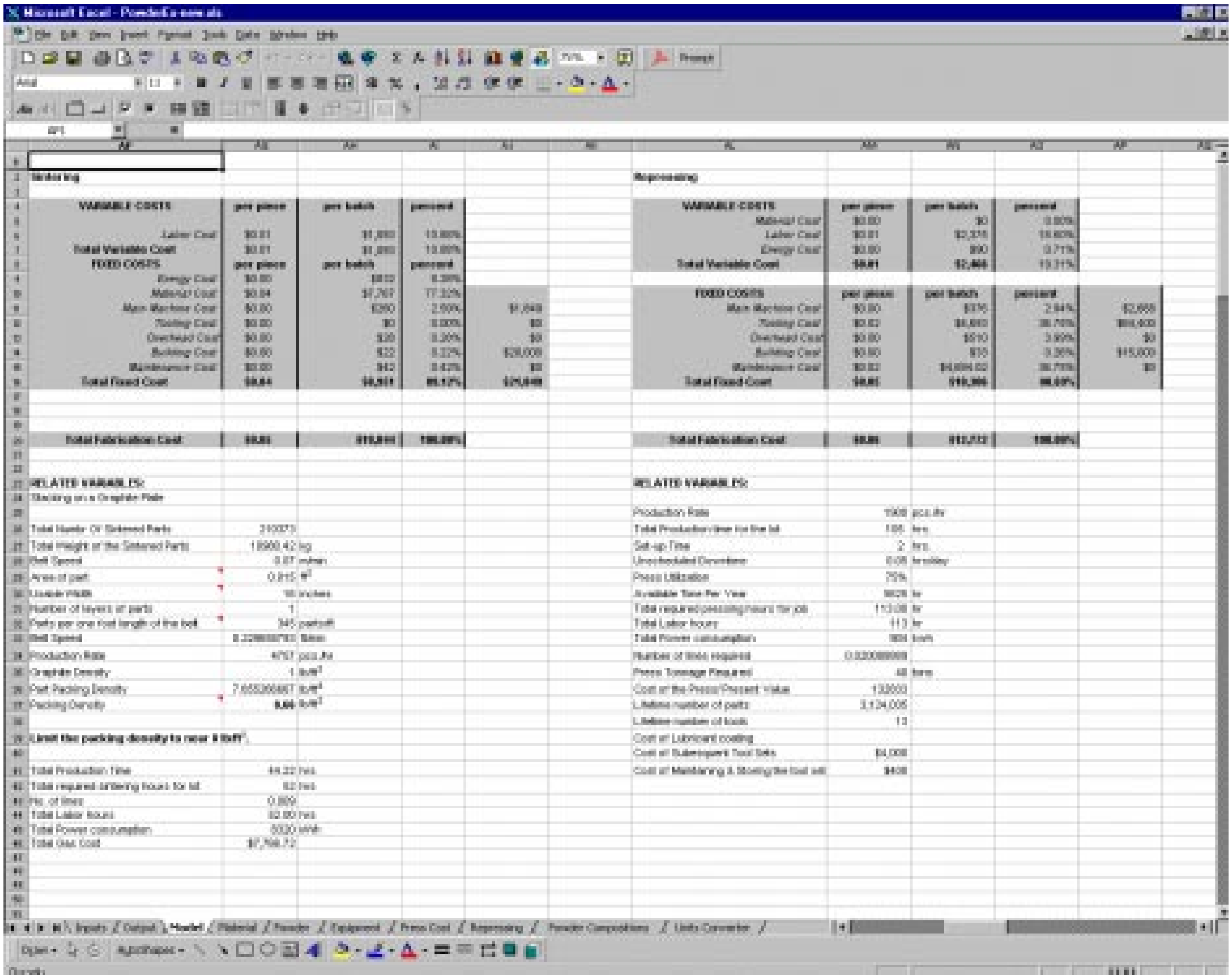
Sometimes a blank graph appears. This could be happen if the number plotted is out of scale. By right-clicking on the axis and formatting the axis, one can change the scale, so that the plotted curve is visible on the graph. The ***Output*** worksheet, with the zoom set on a lower magnification, illustrates all of the resulting tables and graphs below.



2.3 Model Worksheet

All calculations are done and all manipulations of input parameters take place in the ***Model*** worksheet. Most of the cells in this sheet are referenced to other specific cells, and any inadvertent change in this worksheet can distort the final output. If the user wants to reprogram the ***Model*** worksheet, it is advisable to make a copy of the technical cost model. Various inputs from ***Inputs***, ***Powder***, ***Material***, ***Equipment***, ***Press Cost***, and ***Repressing*** are linked to the ***Model*** worksheet and the results are linked to the ***Output*** worksheet. All the important formulas and calculations are explained in this section. Each process step is broken down into fixed and variable costs.

As seen below, each manufacturing step is broken down into its respective constituents.



A. Mixing / Blending Powder Input

Production Rate & Number of Lines: The user enters the time to mix each lot in the mixer. If the capacity or the production rate of the mixer is such that three lots are necessary to mix the required quantity of powder, the model calculates a total mixing time by multiplying the time to mix one lot by the number of lots. The set-up time (if any) is also added to give the total mixing time. Unplanned downtime (hrs/hrs of production time) is considered in the calculation as well. To calculate the number of lines, the total production time available in a year depends on the number of days, shifts and hours that the plant is in operation. The ratio of production time needed to the total time available gives the number of lines of equipment needed.

Calculation of Power: For each type of equipment, a power rating in kilowatts (kW) and a nominal operating efficiency are required. After the model determines the total time for which it would be in use, it calculates the kilowatt-hours (kWh) and divides by the operating efficiency to determine the actual power being drawn from the electrical outlet. Multiplying this with the cost per kWh ($/kWh) gives the total cost of energy for this process step.

Calculation of Labor Costs: The ***Inputs*** worksheet, under exogenous data, solicits information on direct worker wages per line for all the processes. This input multiplied by the total production time and the wages per hour gives the labor costs for a particular process step. Indirect Labor, which includes the supervisors, machine-setters, etc., is also included. Indirect Laborers are assumed to be a percentage of the direct laborers. Wages for a machine operator for the year of 1998 was $17.27/hr, including benefits.

Calculation of Material Costs: Material Costs involve the cost of base powder, lubricants and alloying additives. Once the user has selected the type of iron powder and the alloying additions, the model calculates the cost per pound of the mix and displays it on the ***Inputs*** worksheet. The user can override if desired. The cost per pound is multiplied by the total pounds of the powder needed for the complete lot and results in a total material cost.

B. Molding

Calculation of the Tonnage: After the user chooses the base powder, the model extracts information on the powder from the ***Powder*** worksheet. Depending on the required green density, the model calculates the compaction pressure (tsi) needed to press the part. This pressure is multiplied by the projected area to give the required press tonnage (tons).

Calculation of Cycle Time: The calculation of cycle time is based on the complexity index, which in turn depends on the part complexity and the tonnage needed to press the part. Complexity indices are assigned by part class to facilitate calculation of the cycle times in the model. Class I is assigned a value of 2.5, class II is 2.0, class III is 1.5, and class IV is 1.0. For example, a class II gear that has a part complexity of 2 and requires 40 tons to press the part, and the model calculates a cycle time of 4.29 seconds. This part had an actual cycle time of 5 seconds. The model is fairly close in its estimation of the cycle time. Nevertheless there is an override available.

Calculation of Production Rate: The calculations done here are similar to the calculations done in the Mixing/Blending Powder Input step.

Calculation of Power: The calculations done here are similar to the calculations done in the Mixing/Blending Powder Input step.

Calculation of Labor Costs: The calculations done here are similar to the calculations done in the Mixing/Blending Powder Input step.

C. Pre-Sintering & D. Sintering

Calculation of Material Costs: The materials used in sintering include different gases for the sintering atmospheres:

- Hydrogen
- Hydrogen-Nitrogen
- Endothermic
- Dissociated Ammonia

The model uses the information on the flow rate of the gases (CFH) provided by the user and calculates the cost of the atmosphere.

Calculation of Power: The calculations done here are similar to the calculations done in the Mixing/Blending Powder Input step. All the furnaces are assumed to electrically powered.

Calculation of Production Rate & Number of Lines: The model asks the user for uses the cycle time in high heat zone (minutes) and calculates the belt speed needed to achieve it (ft/min). The part area is known and hence the model can calculate the number of parts that can be accommodated on foot length of the belt (parts/ft). A parts producer can stack more than one layer of parts.

Production Rate (parts/hr) = Belt Speed (ft/min)* Parts per feet (parts/ft)*Number of layers*60

The number of lines is calculated as before.

Calculation of Labor Costs: The calculations done here are similar to the calculations done in the Mixing/Blending Powder Input step.

E. Repressing

Calculation of Production Rate & Number of Lines: A graph in the ***Repressing*** sheet has the sizing tonnage on the x-axis and the production rate (pcs/hr) on the y-axis. Once the tonnage is known, the model calculates the production rate. The number of lines is calculated as before.

The labor and power costs are calculated as before in the mixing/blending step.

F. Tumbling

Tumbling is a secondary operation, which is not always carried out. The tumbling time and number of parts per batch are the two significant inputs that determine the production rate and the number of hours needed for tumbling. The calculations for labor and power are done as before. The cost of tumbling is not very significant.

G. Machining

In an effort to reduce tooling costs, secondary machining steps can be explored. The model provides three common machining options. Cycle times and the number of features are important in determining the number of hours required for each particular operation. To more accurately estimate power consumption, the energy per unit volume of a specific material is required. The energy requirement value for specific machining processes can be found in any engineering materials handbook. The model calculates the total amount of energy required to remove a volume of material, based on feature dimensions and cycle times. Labor is calculated as before. The cost of machining for each step is significant, especially when more than one step is required (i.e., adding an annular ring versus drilling, facing and milling an annular ring).

H. Heat Treatment

The heat treatment step allows the user a variety of options for in-house heat treatment. If the option is explored to treat the material in-house, the user has a variety of options from which to choose. Depending on the material requirements, the user can perform carburizing, austenitize, quench and temper, or steam treatment operations. For the process selected, the user must provide batch size, and cycle times to determine the amount of time required for heat treatment, and pertinent equipment information for calculation of capital costs. The calculations for labor and power are made as explained previously.

I. Inspection Costs

The final audit step can be turned on or off depending on whether there is any final inspection done. The model assumes that an SPC system is installed to check the parts online, which would be added to the cost per piece irrespective of whether the final audit is turned on or off.

Depending on how much time it takes to audit one part, the labor costs are calculated. Also the cost of gear tester or metrology equipment is amortized over a certain life.

3. Definition of Key Inputs Parameters

The input parameters located in the ***Inputs*** worksheet are described, defined or listed in this section. As the number of input parameters is large, it is not possible to define each and every input.

A. Inputs Worksheet

The ***Input*** worksheet contains a number of input parameters, which a user fills in. Explanations of some of the more critical inputs are given below.

Product Life

Product Life is the duration in years of the contract to manufacture a particular component.

Days per Year

This input defines the number of days in a year for which the plant would be running.

Electricity Cost

The unit cost of electrical energy in ($/kWh).

Capital Recovery Rate

This is the interest rate at which you would want to amortize the machinery. A higher rate indicates a faster return on investment.

Equipment Life

This parameter provides the number of years over which the capital investment in equipment is recovered. The equipment life may not necessarily reflect the physical life of the equipment when accounting needs require that capital investments be recovered in an accelerated time frame.

Building Unit Cost

The cost per area of building new facilities.

Building Life

The effective life of the building, to be used in the straight line depreciation of the total building investment.

Downtimes

This input determines the planned downtime of facility, which is characterized in two ways: by the number of hours per day that the workers are paid and by the number of hours per day that the workers are unpaid. These inputs inherently determine the number of hours that the facility is planned to operate per day.

Auxiliary Equipment Cost

The cost of auxiliary equipment is estimated as a percentage of the investment in the primary equipment. The average value for the auxiliary equipment cost is, in part, a function of the scale of the operation, and directly affects the equipment investment. For small operations, auxiliary equipment is generally a larger percentage of the total equipment investment.

Scrap Rate

Material Scrap and Part Rejection reflect the loss of material that occurs in manufacturing. Each is specified as a percentage of incoming material mass. For instance, if 10 kg of incoming material is required to make an 8-kg part, then the scrap percentage is 20%. Similarly, if 100 parts must be attempted to yield 98 good parts, then the rejection rate is 2%. Note that both values are bounded by 0% and 100%.

4. Description of Key Outputs

These are the various outputs that ***PowderEx*** can calculate for the user. It includes various sensitivities and cost breakdowns.

A. Cost Breakdown & Pie Chart

The various costs calculated in the ***Model*** worksheet are displayed on this sheet in an orderly fashion. There are two tables with cost breakdowns and their associated pie charts. One pie chart gives a visual picture and the percentage breakdown into individual process steps. The other pie chart gives a visual breakdown into fixed and variable costs.

B. Impact of Reject Rates on Cost per Piece

This graph shows how the cost per piece changes upon change in the reject rate.

C. Sensitivity to Production Volume

This chart shows how the cost per piece changes as the volume per run is changed. The fact that some cost systems estimate the same cost for a volume of 1000 or 10,000 is completely wrong. As the production volume increases the cost per piece has to go down as machines are utilized better, and tooling cost, which is a major factor can be amortized over a larger number of parts.

D. Effect of Molding Cycle Time on Part Cost

This chart indicates the sensitivity of part cost with the molding cycle time.

E. Effect of Electricity Costs on Part Cost

This chart indicates the sensitivity of part cost with the cost of electricity.

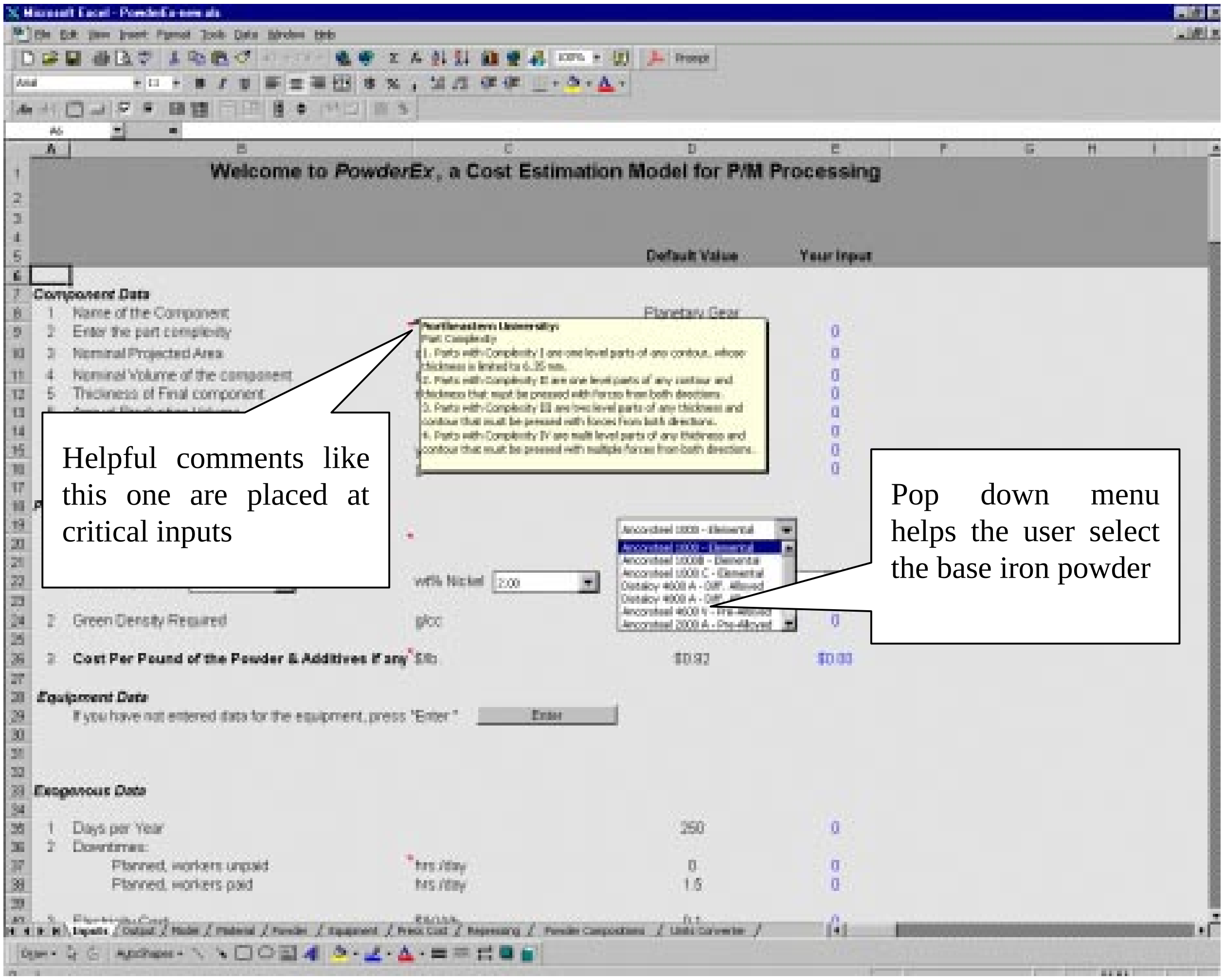
All of these charts are dynamic in nature. The values and the curves will change on any change in the inputs. If the graph is blank, increase or decrease the scale until the plotted curve is back in the graph.

5. User Tutorial

The easiest way to become more familiar with the ***PowderEx*** model is to look at an existing component for which the results were generated. In this tutorial, the inputs for a spur gear made of FN-0200 alloy powder, with an annular ring milled into one surface, and carburized in-house, are used to demonstrate how various worksheets, macros, and pop-down menus work.

The model opens on the ***Inputs*** worksheet, where the user must enter data. The first step in data entry is the *Component Data*, which does not need much explanation. All the part characteristics are entered.

The next is *Powder Properties*, and as the screen display below shows, there is a list of iron-based powders from which to choose. The material selected in this case is Ancorsteel 1000C.



Welcome to *PowderEx*, a Cost Estimation Model for P/M Processing

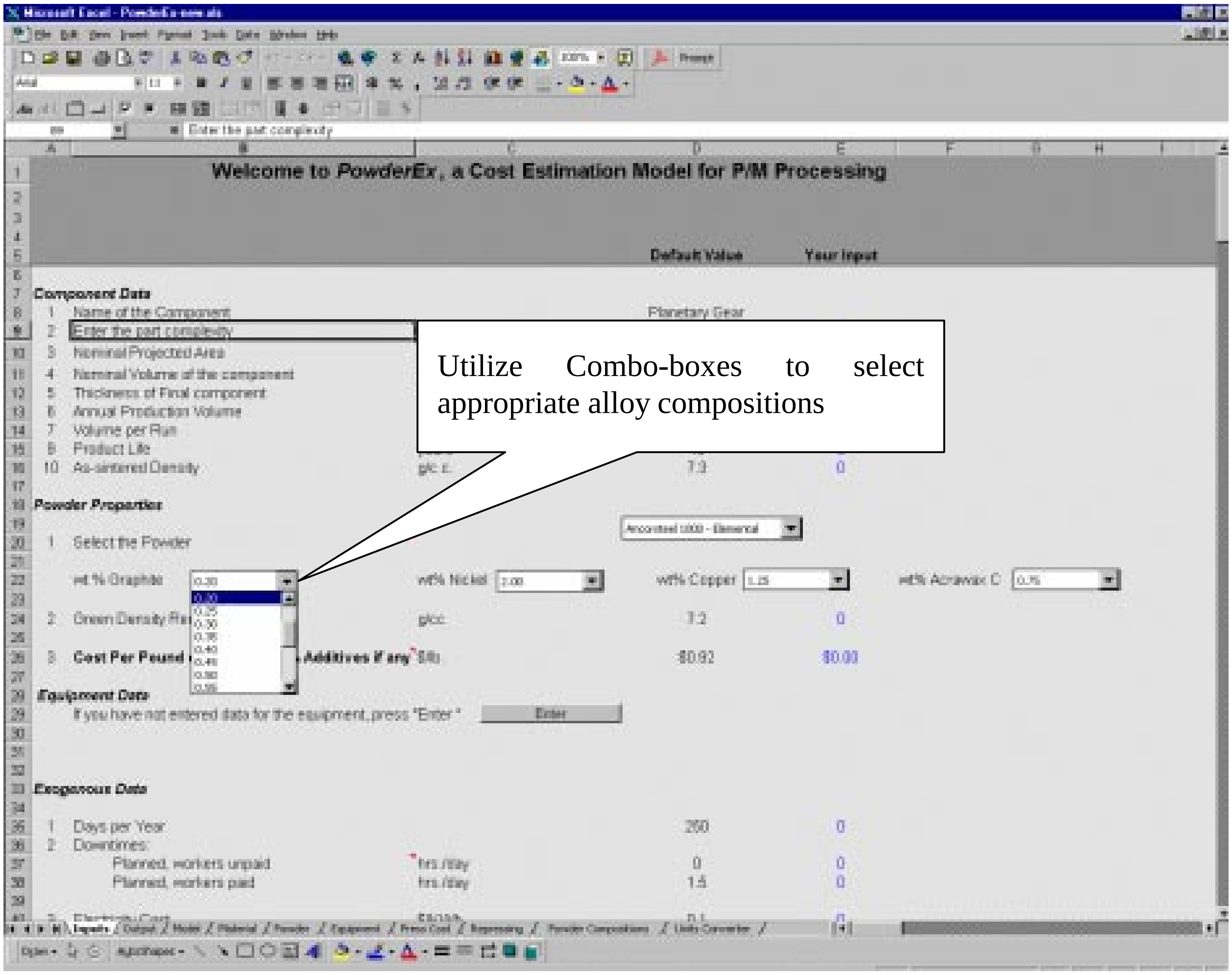
			Default Value	Your Input
Component Data				
1	Name of the Component		Planetary Gear	
2	Enter the part complexity			0
3	Nominal Projected Area			0
4	Nominal Volume of the component			0
5	Thickness of Final component			0
		wt% Nickel 2.00		
2	Green Density Required	g/cc		0
3	**Cost Per Pound of the Powder & Additives if any**	$/lb	$0.92	$0.00
Equipment Data				
	If you have not entered data for the equipment, press "Enter".			
Exogenous Data				
1	Days per Year		250	0
2	Downtimes:			
	Planned, workers unpaid	hrs /day	0	0
	Planned, workers paid	hrs /day	1.5	0

Northeastern University:
Part Complexity
1. Parts with Complexity I are one level parts of any contour, whose thickness is limited to 6.35 mm.
2. Parts with Complexity II are one level parts of any contour and thickness that must be pressed with forces from both directions.
3. Parts with Complexity III are two level parts of any thickness and contour that must be pressed with forces from both directions.
4. Parts with Complexity IV are multi level parts of any thickness and contour that must be pressed with multiple forces from both directions.

Helpful comments like this one are placed at critical inputs

Pop down menu helps the user select the base iron powder

The next step is to add the alloying elements, which is done by selecting appropriate percentages of required elements. In this case, the steel composition is FN-0200, thus 0.2% should be selected for graphite, 2% should be selected for nickel, 1.25% should be selected for copper, and 0.75% should be selected for Acrawax C.

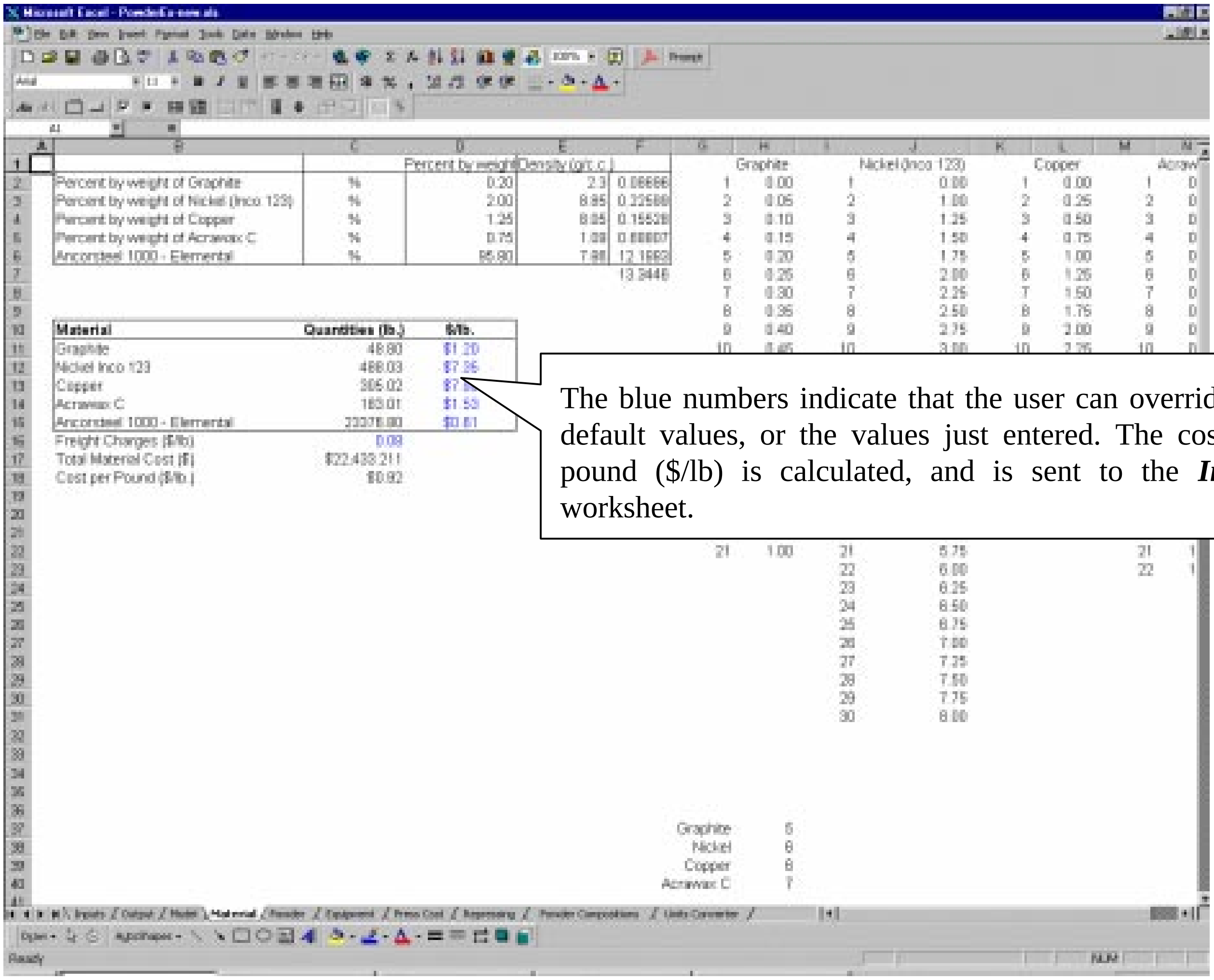


Welcome to *PowderEx*, a Cost Estimation Model for P/M Processing

			Default Value	Your Input
Component Data				
1	Name of the Component		Planetary Gear	
2	Enter the part complexity			
3	Nominal Projected Area			
4	Nominal Volume of the component			
5	Thickness of Final component			
6	Annual Production Volume			
7	Volume per Run			
8	Product Life			
10	As-sintered Density	g/c.c.	7.3	0
Powder Properties				
1	Select the Powder		Ancorsteel 1000 - Elemental	
	wt.% Graphite 0.20	wt% Nickel 2.00	wt% Copper 1.25	wt% Acrawax C 0.75
2	Green Density Re	g/cc	7.2	0
3	**Cost Per Pound ... Additives if any**	$/lb	$0.92	$0.00
Equipment Data				
	If you have not entered data for the equipment, press "Enter."	Enter		
Exogenous Data				
1	Days per Year		260	0
2	Downtimes:			
	Planned, workers unpaid	hrs./day	0	0
	Planned, workers paid	hrs./day	1.5	0

Utilize Combo-boxes to select appropriate alloy compositions

This information is entered into pop down menus and then relayed to the ***Material*** worksheet, which is shown below.



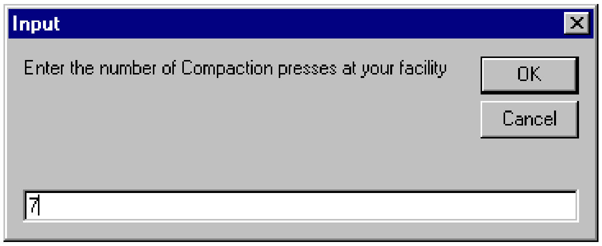
		Percent by weight	Density (g/c.c.)	
Percent by weight of Graphite	%	0.20	2.3	0.08696
Percent by weight of Nickel (Inco 123)	%	2.00	8.85	0.22599
Percent by weight of Copper	%	1.25	8.05	0.15528
Percent by weight of Acrawax C	%	0.75	1.09	0.68807
Ancorsteel 1000 - Elemental	%	95.80	7.88	12.1663
				13.3446

Material	Quantities (lb.)	$/lb.
Graphite	48.80	$1.20
Nickel Inco 123	488.03	$7.26
Copper	305.02	$7.
Acrawax C	183.01	$1.53
Ancorsteel 1000 - Elemental	23378.80	$0.61
Freight Charges ($/lb)	0.08	
Total Material Cost ($)	$22,433.211	
Cost per Pound ($/lb.)	$0.92	

Graphite	5
Nickel	8
Copper	8
Acrawax C	7

The blue numbers indicate that the user can override the default values, or the values just entered. The cost per pound ($/lb) is calculated, and is sent to the ***Inputs*** worksheet.

Back on the ***Inputs*** worksheet, information regarding the equipment must be entered. Upon pressing the "Enter" button under Equipment data, a dialog box opens in the following manner:



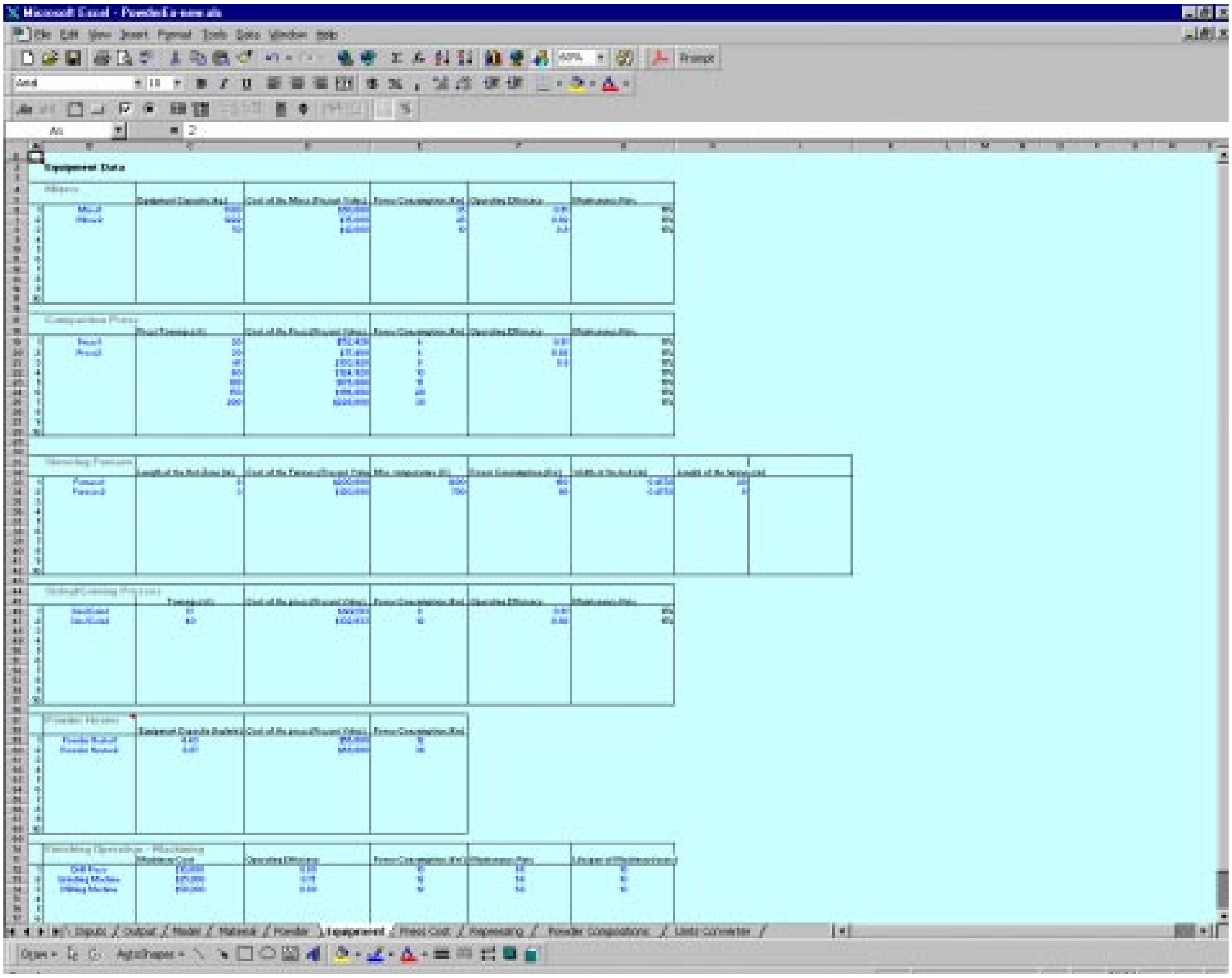
Enter the number of Compaction presses at your facility

7

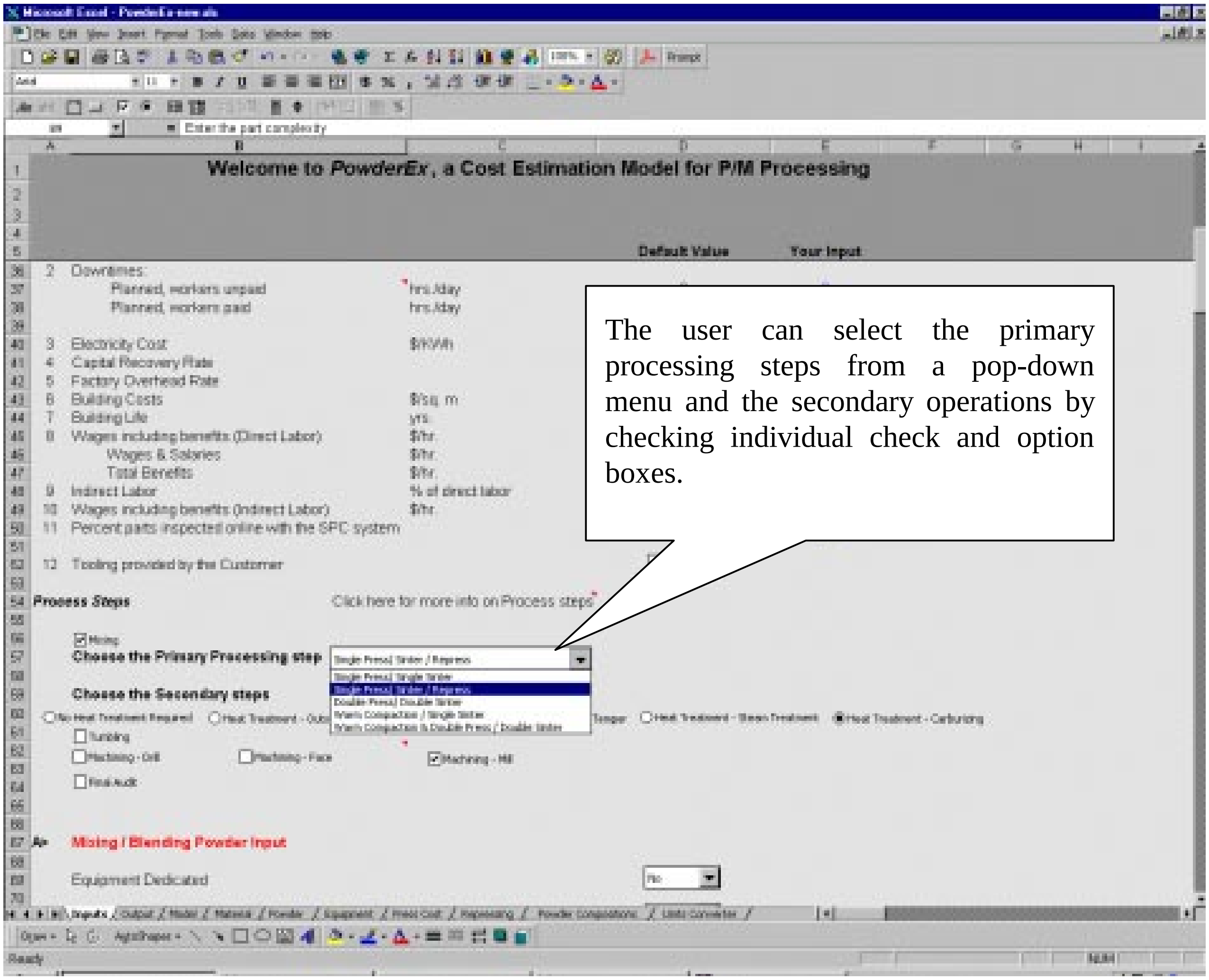
Enter the number of Sintering Furnaces at your facility

2

The number of lines of each type of equipment at the facility are recorded in the dialogue boxes. The user is then prompted to go to the ***Equipment*** worksheet.



The ***Equipment*** worksheet requires the user to enter specific information for each line of equipment, such as cost, capacity, power rating, etc. This will allow the model to more accurately estimate the costs, since actual numbers for a facility can be entered. Once this is done, the user returns to the ***Inputs*** worksheet and completes input for the *Exogenous Data*. This is a fairly simple exercise, but if clarification if required, return to Section 4, where definitions of key inputs are given.


Enter the part complexity

Welcome to *PowderEx*, a Cost Estimation Model for P/M Processing

Default Value

Your Input

2 Downtimes:

Planned, workers unpaid hrs./day

Planned, workers paid hrs./day

3 Electricity Cost $/KWh

4 Capital Recovery Rate

5 Factory Overhead Rate

6 Building Costs $/sq. m

7 Building Life yrs.

8 Wages including benefits (Direct Labor) $/hr.

Wages & Salaries $/hr.

Total Benefits $/hr.

9 Indirect Labor % of direct labor

10 Wages including benefits (Indirect Labor) $/hr.

11 Percent parts inspected online with the SPC system

12 Tooling provided by the Customer

Process Steps Click here for more info on Process steps

☑ Mixing

Choose the Primary Processing step Single Press/ Sinter / Repress

Choose the Secondary steps

○ No Heat Treatment Required ○ Heat Treatment - Quench ... Temper ○ Heat Treatment - Steam Treatment ● Heat Treatment - Carburizing

☐ Tumbling

☐ Machining - Drill ☐ Machining - Face ☑ Machining - Mill

☐ Final Audit

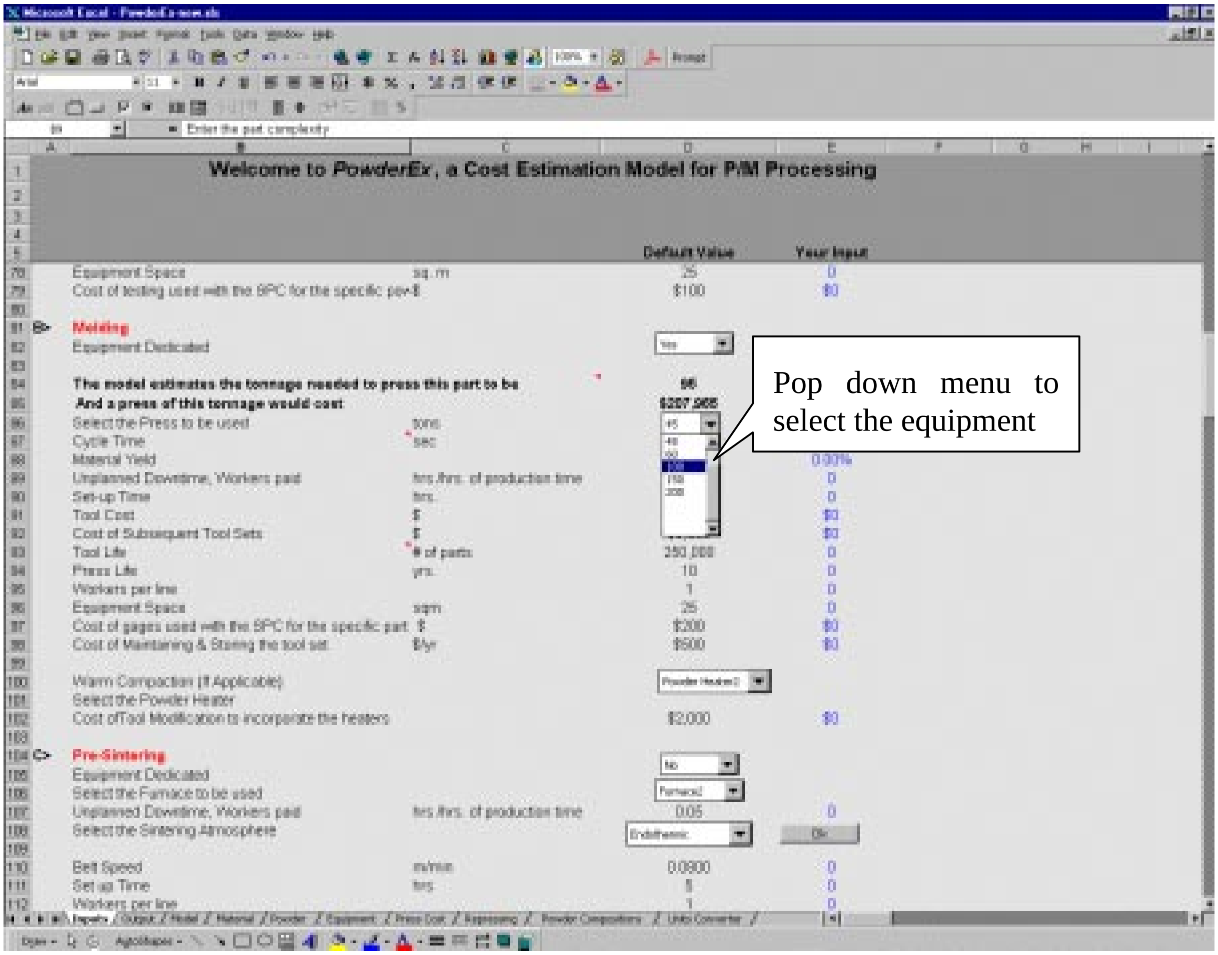
Mixing / Blending Powder Input

Equipment Dedicated No

The user can select the primary processing steps from a pop-down menu and the secondary operations by checking individual check and option boxes.

Back on the ***Inputs*** worksheet, the user must select information in the *Process Steps* section, where specific process step options are shown above. Primary process steps choices include: i) single press / single sinter, ii) single press / sinter/repress, iii) double press / double sinter, iv) warm compaction / single sinter, and v) warm compaction and double press / double sinter. The secondary step option boxes include any of four heat treatments, a tumbling step, three optional machining operations, and final audit.

Scrolling down the ***Inputs*** worksheet, information on specific process steps must be entered. If a particular step is turned off, the user need not put any information on that step. The first step is Mixing /Blending Powder Input. Enter the information, and then move on to the next step, i.e., Molding. The model estimates the tonnage based on the powder and the green density and displays it on the sheet, with an approximate cost for the equipment. Press Costs are taken from a vendor and that information can be found in ***Press Cost*** worksheet. This will help the user select an appropriate tonnage press. A pop down menu allows the user to select one of the presses that was just provided information in the ***Equipment*** worksheet, as shown in the next illustration. This information is used in the model to calculate the production time and various costs.

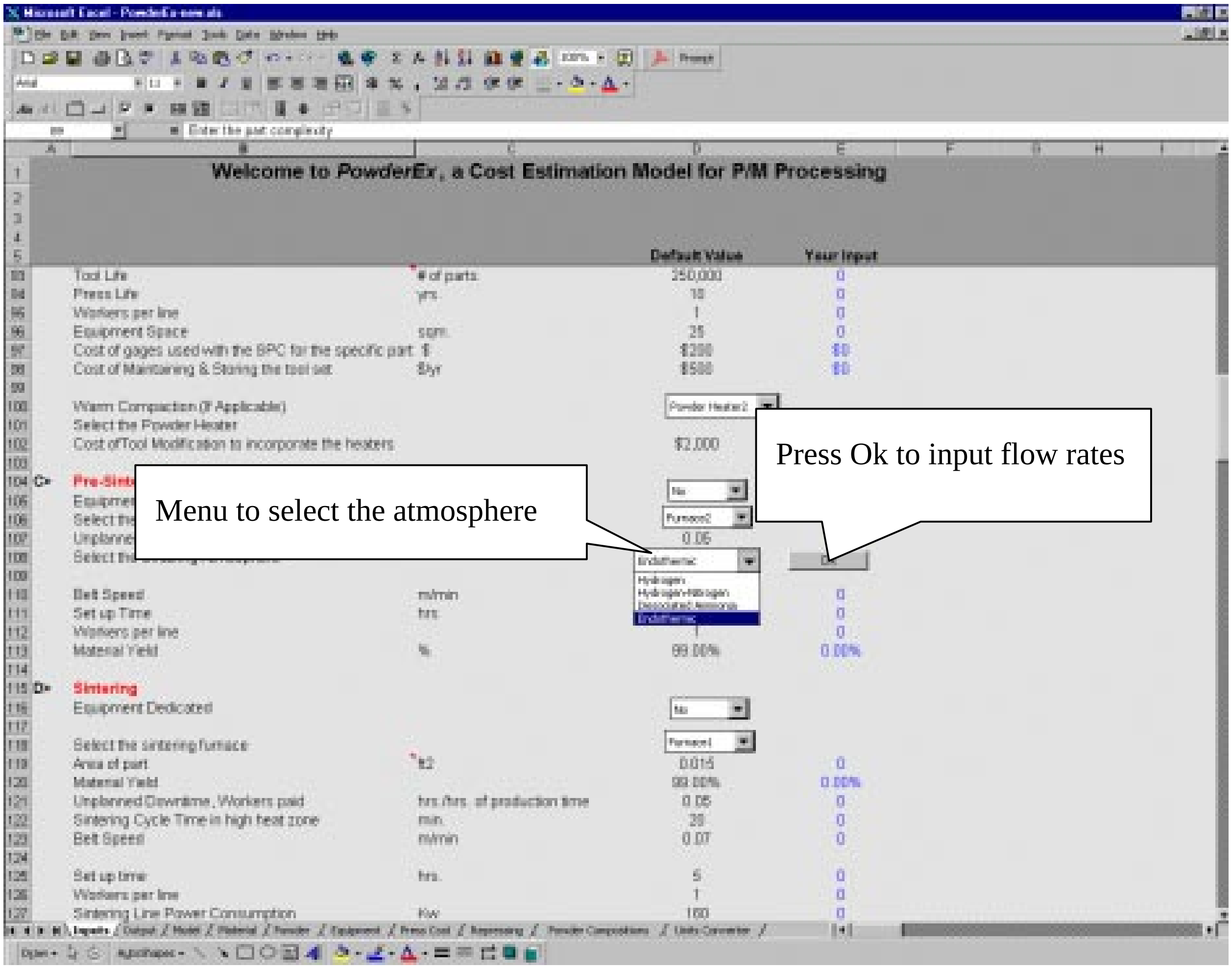


Welcome to *PowderEx*, a Cost Estimation Model for P/M Processing

			Default Value	Your Input
78	Equipment Space	sq. m	25	0
79	Cost of testing used with the SPC for the specific pov	$	$100	$0
80				
81	**Molding**			
82	Equipment Dedicated		Yes	
83				
84	**The model estimates the tonnage needed to press this part to be**		**98**	
85	**And a press of this tonnage would cost**		**$207,965**	
86	Select the Press to be used	tons	45 45 60 100 150 200	
87	Cycle Time	sec		
88	Material Yield			0.00%
89	Unplanned Downtime, Workers paid	hrs./hrs. of production time		0
90	Set-up Time	hrs.		0
91	Tool Cost	$		$0
92	Cost of Subsequent Tool Sets	$		$0
93	Tool Life	# of parts	250,000	0
94	Press Life	yrs.	10	0
95	Workers per line		1	0
96	Equipment Space	sqm	25	0
97	Cost of gages used with the SPC for the specific part	$	$200	$0
98	Cost of Maintaining & Storing the tool set	$/yr	$500	$0
99				
100	Warm Compaction (If Applicable)		Powder Heater2	
101	Select the Powder Heater			
102	Cost of Tool Modification to incorporate the heaters		$2,000	$0
103				
104	**Pre-Sintering**			
105	Equipment Dedicated		No	
106	Select the Furnace to be used		Furnace2	
107	Unplanned Downtime, Workers paid	hrs./hrs. of production time	0.05	0
108	Select the Sintering Atmosphere		Endothermic	Ok
109				
110	Belt Speed	m/min	0.0900	0
111	Set up Time	hrs	5	0
112	Workers per line		1	0

Pop down menu to select the equipment

Sintering or Pre-Sintering follows Molding, where an atmosphere is selected for the furnace with the flow rates, along with the usual inputs. A screen print is shown below:



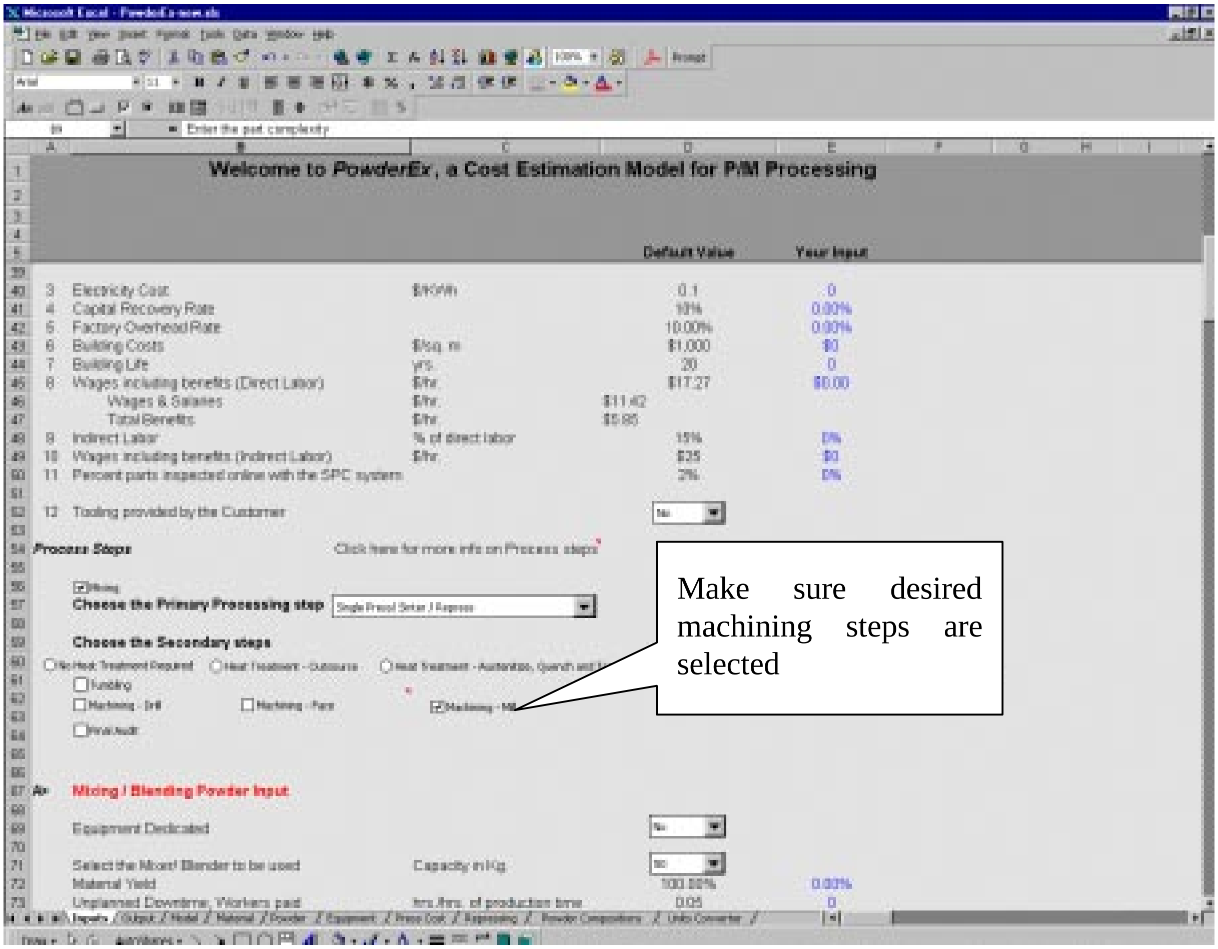
Welcome to *PowderEx*, a Cost Estimation Model for P/M Processing

				Default Value	Your Input
93		Tool Life	# of parts	250,000	0
94		Press Life	yrs.	10	0
95		Workers per line		1	0
96		Equipment Space	sqm.	25	0
97		Cost of gages used with the SPC for the specific part	$	$200	$0
98		Cost of Maintaining & Storing the tool set	$/yr	$500	$0
99					
100		Warm Compaction (If Applicable)		Powder Heater2	
101		Select the Powder Heater			
102		Cost of Tool Modification to incorporate the heaters		$2,000	
103					
104	C>	**Pre-Sint**			
105		Equipme		No	
106		Select the		Furnace2	
107		Unplanne		0.05	
108		Select the		Endothermic Hydrogen Hydrogen-Nitrogen Dissociated Ammonia Endothermic	Ok
109					
110		Belt Speed	m/min		0
111		Set up Time	hrs.		0
112		Workers per line		1	0
113		Material Yield	%	99.00%	0.00%
114					
115	D>	**Sintering**			
116		Equipment Dedicated		No	
117					
118		Select the sintering furnace		Furnace1	
119		Area of part	ft2	0.015	0
120		Material Yield		99.00%	0.00%
121		Unplanned Downtime, Workers paid	hrs./hrs. of production time	0.05	0
122		Sintering Cycle Time in high heat zone	min.	20	0
123		Belt Speed	m/min	0.07	0
124					
125		Set up time	hrs.	5	0
126		Workers per line		1	0
127		Sintering Line Power Consumption	Kw	100	0

Press Ok to input flow rates

Menu to select the atmosphere

Repressing is similar to the Molding step, and hence should be dealt in the same way. The cost information of Repressing presses can be found in ***Repressing*** worksheet. Similar information on secondary operations is required from the user.


Welcome to *PowderEx*, a Cost Estimation Model for P/M Processing

				Default Value	Your Input
3	Electricity Cost	$/KWh		0.1	0
4	Capital Recovery Rate			10%	0.00%
5	Factory Overhead Rate			10.00%	0.00%
6	Building Costs	$/sq. m		$1,000	$0
7	Building Life	yrs		20	0
8	Wages including benefits (Direct Labor)	$/hr		$17.27	$0.00
	Wages & Salaries	$/hr	$11.42		
	Total Benefits	$/hr	$5.85		
9	Indirect Labor	% of direct labor		15%	0%
10	Wages including benefits (Indirect Labor)	$/hr		$25	$0
11	Percent parts inspected online with the SPC system			2%	0%
12	Tooling provided by the Customer			No	

Process Steps

Click here for more info on Process steps

☑ Mixing

Choose the Primary Processing step Single Press/ Sinter / Repress

Choose the Secondary steps

○ No Heat Treatment Required ○ Heat Treatment - Outsource ○ Heat Treatment - Austenitize, Quench and

☐ Tumbling

☐ Machining - Drill ☐ Machining - Face ☑ Machining - Mill

☐ Final Audit

Mixing / Blending Powder Input

			Default Value	Your Input
Equipment Dedicated		No		
Select the Mixer/ Blender to be used	Capacity in Kg	50		
Material Yield			100.00%	0.00%
Unplanned Downtime, Workers paid	hrs./hrs. of production time		0.05	0

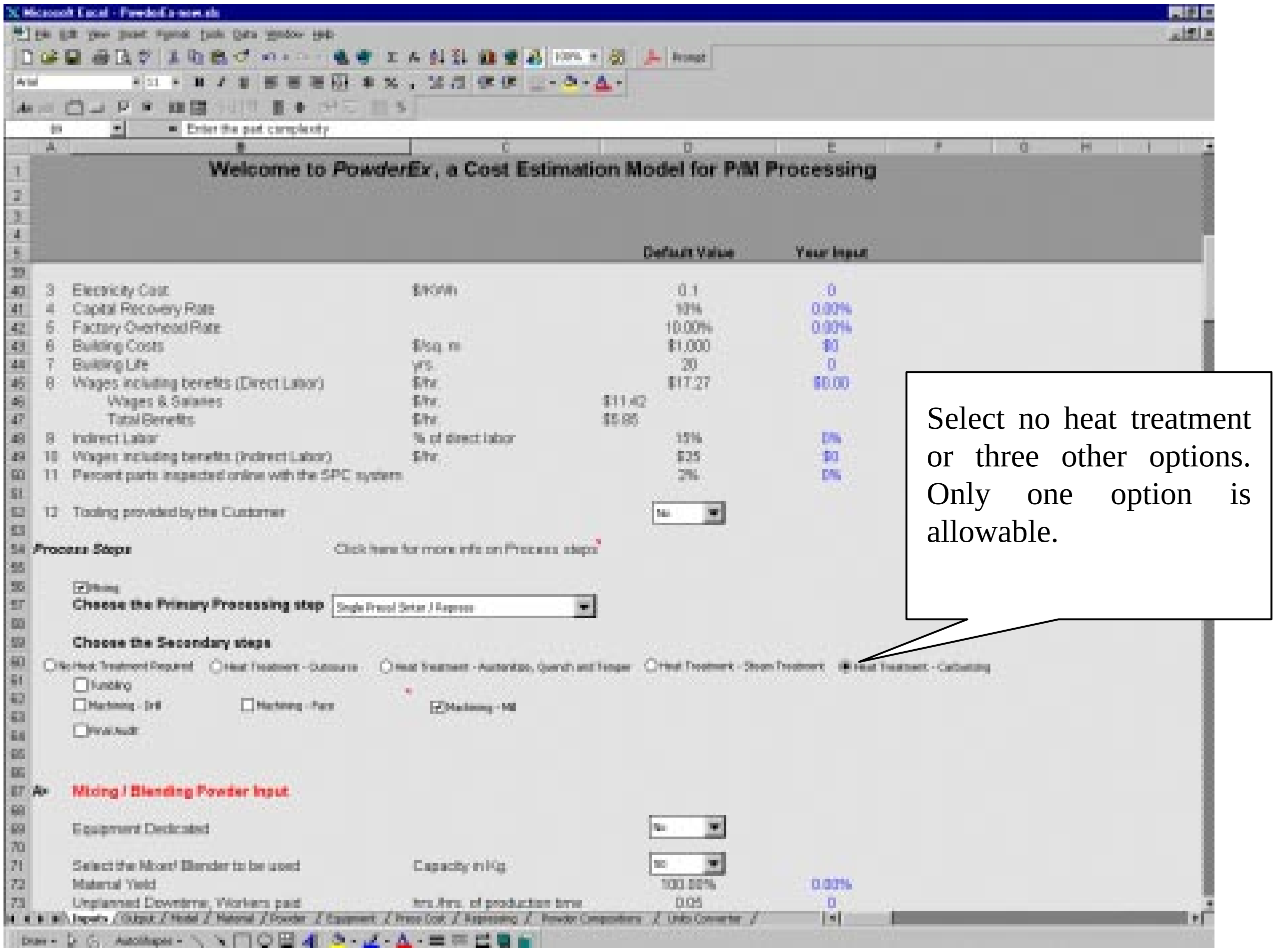
Make sure desired machining steps are selected

Before Heat Treatment, the annular ring must be added to the face of the gear. Selecting the *Machining - Mill* checkbox as seen above, activates the process step.

After the milling step has been checked under *Process Steps*, proceed down to *Machining - Mill*. The required input for this step includes cycle times, feature dimensions, and pertinent tool information. Also, the equipment information at the bottom of the ***Equipment*** worksheet must be verified.

After the machining step, input for heat treatment is required. The Heat Treatment step is set up as an option and only one heat treatment step can be performed. If information is entered in the heat treatment process steps, it will only be implemented if the Heat Treatment option is turned on, at the top of the page under *Process Steps*. To activate the carburizing step, check the carburizing option button as seen below.

Once the carburizing step has been selected, proceed down to step *Heat Treatment – In house – Carburizing*. The required data for this step include furnace capacities, cycle times, and equipment operating parameters similar to those in other steps.



Welcome to *PowderEx*, a Cost Estimation Model for P/M Processing

				Default Value	Your Input
3	Electricity Cost	$/KWh		0.1	0
4	Capital Recovery Rate			10%	0.00%
5	Factory Overhead Rate			10.00%	0.00%
6	Building Costs	$/sq. m		$1,000	$0
7	Building Life	yrs		20	0
8	Wages including benefits (Direct Labor)	$/hr.		$17.27	$0.00
	Wages & Salaries	$/hr.	$11.42		
	Total Benefits	$/hr.	$5.85		
9	Indirect Labor	% of direct labor		15%	0%
10	Wages including benefits (Indirect Labor)	$/hr.		$35	$0
11	Percent parts inspected online with the SPC system			2%	0%
12	Tooling provided by the Customer			No	

Process Steps Click here for more info on Process steps

☑ Mixing

Choose the Primary Processing step: Single Press/ Sinter / Repress

Choose the Secondary steps

○ No Heat Treatment Required ○ Heat Treatment - Outsource ○ Heat Treatment - Austenitize, Quench and Temper ○ Heat Treatment - Steam Treatment ● Heat Treatment - Carburizing

☐ Tumbling

☐ Machining - Drill ☐ Machining - Face ☑ Machining - Mill

☐ Final Audit

Mixing / Blending Powder Input

Equipment Dedicated: No

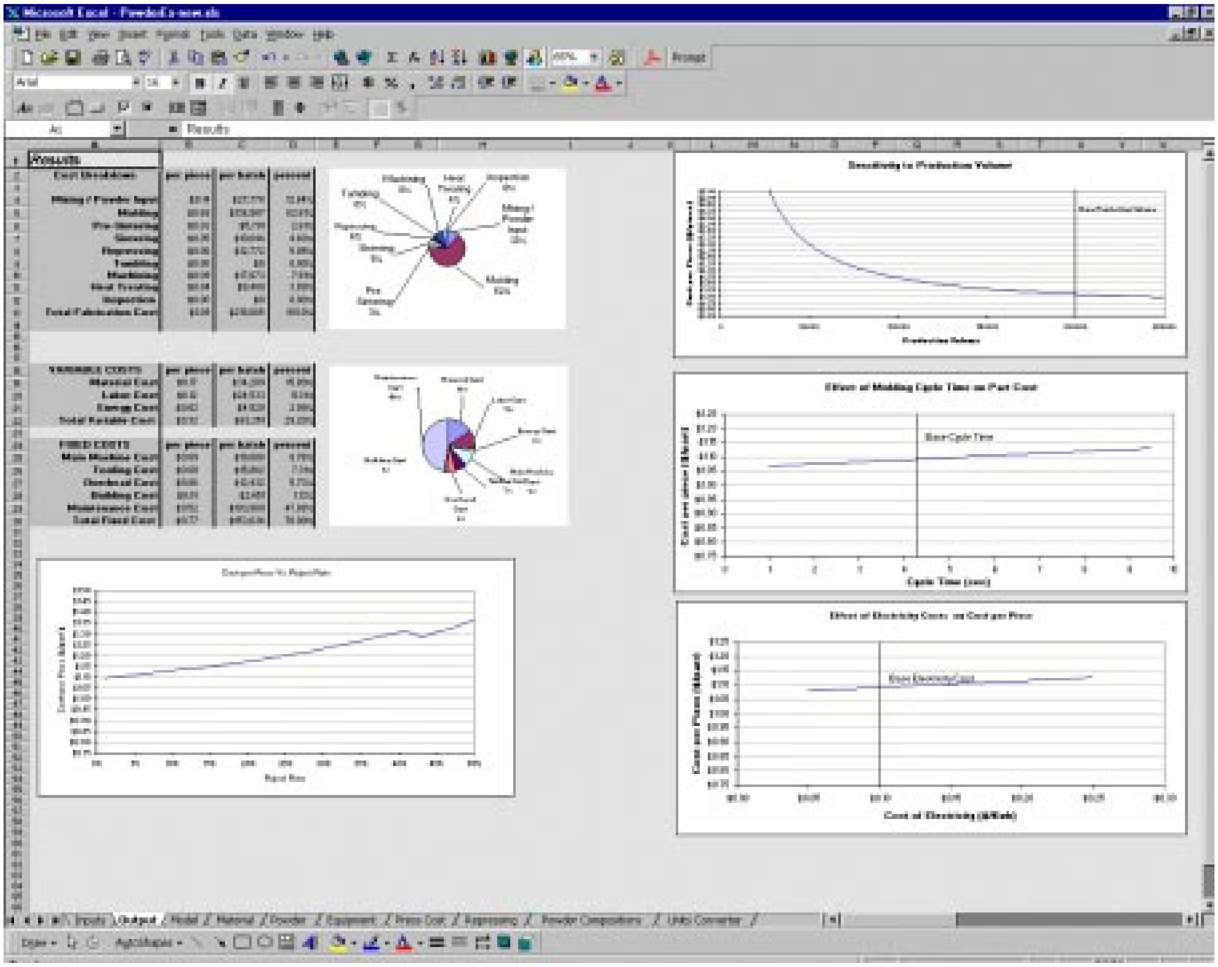
Select the Mixer/ Blender to be used — Capacity in Kg: 50

Material Yield: 100.00% 0.00%

Unplanned Downtime, Workers paid — hrs./hrs. of production time: 0.05 0

Select no heat treatment or three other options. Only one option is allowable.

After you reach the end of ***Inputs*** worksheet, data entry is complete. The ***Model*** worksheet solves hundreds of equations and the results are displayed on the ***Output*** worksheet. A sample output is shown below.



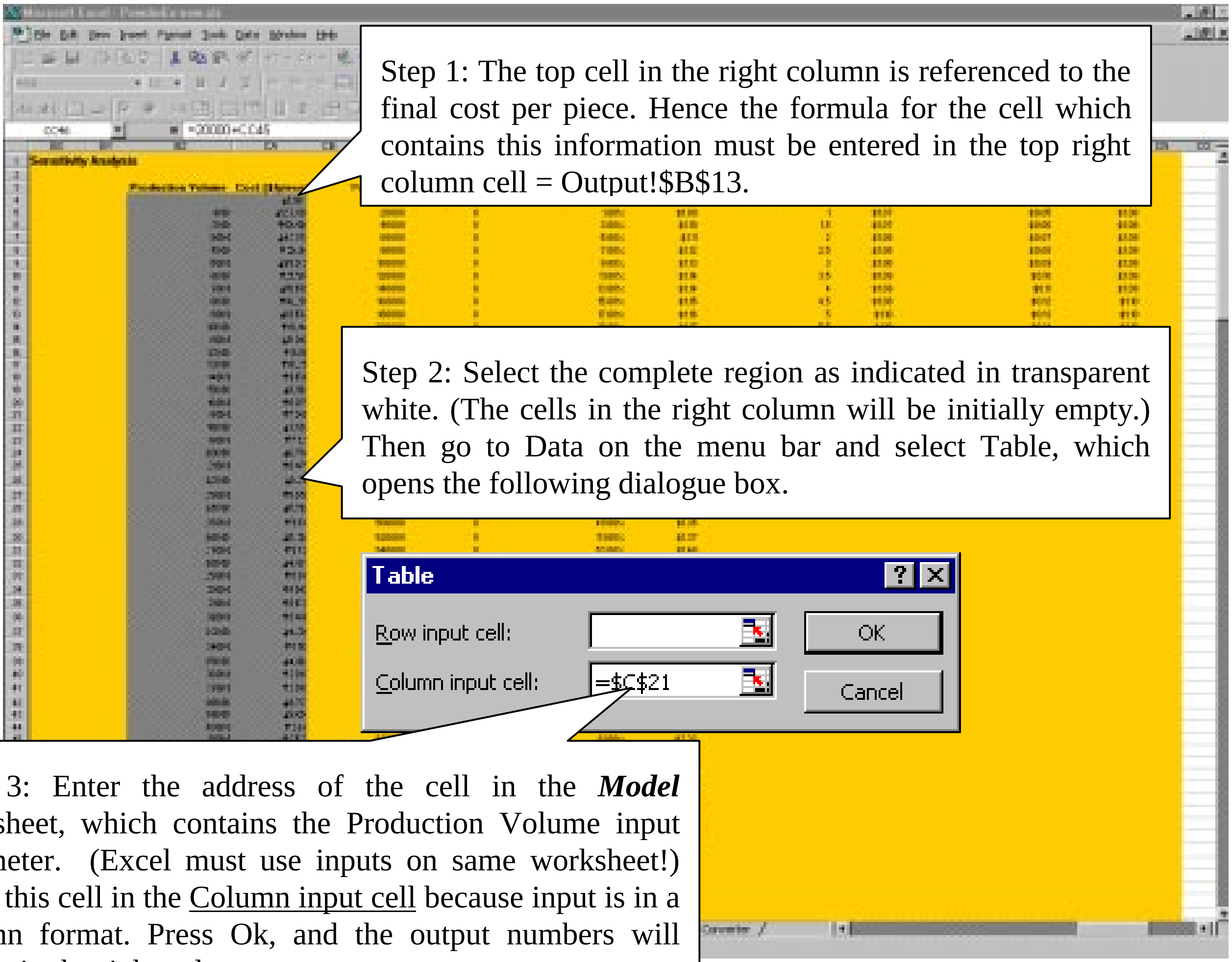
Zooming in would give you a much higher resolution. The outputs and their descriptions are listed in Section 4 of this document.

To reiterate, the model is best learned by experimenting. Questions about the use of the model or this documentation should be directed to the Laboratory for Analysis of Materials Processing at Northeastern University or through the Metals Processing Institute at Worcester Polytechnic Institute.

A. Sensitivity Analysis

Sensitivity analyses indicate how the economics of a particular manufacturing process are affected by changes in the input parameters. If a small variation in a process parameter results in a significant change in the output, the parameter is considered a critical input.

Performing a sensitivity analysis in Excel is relatively easy, as shown in an example below. The graphic below shows how the sensitivity of production volume to the part cost can be generated. First, the user enters a tabular series of inputs for the production volume in a column. Then the top cell in the next column must contain the output of interest. Excel has extensive instructions on generating data tables of this type. Similar sensitivities can be done for other input variables to check their correlation on the final costs and graphs can be created.



Step 1: The top cell in the right column is referenced to the final cost per piece. Hence the formula for the cell which contains this information must be entered in the top right column cell = Output!$B$13.

Step 2: Select the complete region as indicated in transparent white. (The cells in the right column will be initially empty.) Then go to Data on the menu bar and select Table, which opens the following dialogue box.

Table

Row input cell:

Column input cell: =$C$21

Step 3: Enter the address of the cell in the ***Model*** worksheet, which contains the Production Volume input parameter. (Excel must use inputs on same worksheet!) Enter this cell in the Column input cell because input is in a column format. Press Ok, and the output numbers will appear in the right column.

THE EFFECTS OF MARKET AND LEARNING ORIENTATION ON ORGANIZATIONAL CAPABILITIES

Kevin G. Celuch
Department of Marketing
Illinois State University
Normal, IL 61790
Phone: (309) 438-7077
Fax: (309) 438-5510
E-mail: kgceluc@ilstu.edu

Chickery J. Kasouf
Department of Management
Worcester Polytechnic Institute
Worcester, MA 01609

Venkatakrishna Peruvemba
Motorola
Schaumburg, IL 60193

October 12, 2000

The authors would like to thank the Alfred P. Sloan Foundation and the Carl Gunnard Johnson P/M Research Center at Worcester Polytechnic Institute for their support of this work.

Kevin G. Celuch (Ph.D., Syracuse University) is a Professor of Marketing at Illinois State University. His research interests are in marketing communication, measurement, and buyer-seller relationships. His work has appeared in *Psychology & Marketing, Journal of Applied Social Psychology, Industrial Marketing Management, Journal of Business and Psychology* as well as other journals and national and international conferences.

Chickery J. Kasouf (MBA, Ph.D., Syracuse University) is an Associate Professor of Marketing at Worcester Polytechnic Institute. His research interests are in marketing strategies, marketing information management, and innovation management. His work has appeared in *Psychology & Marketing, Industrial Marketing Management, Journal of Consumer Satisfaction, Dissatisfaction, and Complaining Behavior, International Journal of Powder Metallurgy* as well as other journals and national and international conferences.

Venkatakrishnan Peruvemba (MBA, Illinois State University) is a Financial Analyst in global non-production procurement at Motorola in Schaumburg, Illinois.

Managers in a variety of industries face many complex challenges and opportunities, especially as rapid information technology change affects business processes in high technology and many formerly low technology environments. Within this context, firms must evaluate not only specific strategic moves but also fundamental premises underlying their business strategies as a means of gaining and sustaining competitive advantage [1]. To this end, two complementary literature streams have developed and are now converging: research addressing market orientation and organizational learning.

Market orientation has its roots in the 1950s and early 1960s, with authors such as Drucker [2] and Keith [3] who suggested that marketing is a perspective that should permeate the organization. This evolved into the marketing concept, a customer centered view of business definition that dominated marketing textbooks of the 1970s and beyond [4]. During the 1990s, this concept developed into market orientation, giving it a theoretical and empirical foundation that explicitly linked a responsive organization to performance measures such as profitability and market share [e.g., 5, 6]. While there is some variability in operationalizing its definition, market orientation, typically focuses on information gathering, dissemination, and use [7] or customer orientation, competitor orientation, and interfunctional coordination [5, 8]. Information flow and use is at the center of either conceptualization.

The literature on organizational learning, with its roots in the work of researchers such as Argyris and Schon [9] and Fiol and Lyles [10] addresses how organizations change with the acquisition of knowledge. As Slater and Narver [11] suggest, organizational learning is the development of new knowledge or insights that have the potential to affect behavior. Perhaps the importance of learning is most forcefully articulated by the often repeated quote by deGeus [12] that the only truly sustainable competitive advantage of a firm is its ability to learn.

Given market orientation s emphasis on information use, its link with learning is an area of marketing research that has potential implications for theory and practice. Slater and Narver [11] called for research in this area because of the possible impact that learning has on competitive advantage. The role of information processing can, in some circumstances, depend on questioning market assumptions as well as learning. For example, Christensen [13] argued that managing disruptive change, i.e, technology shifts with a fundamentally new value proposition are often missed by industry leaders because their largest customers do not recognize the value of the change. Thus, a firm can be too close to the customer. Business success in these situations depends on the firm s ability to learn independent of customers.

Thus, the relative roles of a market orientation and learning orientation and their impact on the organization provide a fertile arena for research. Baker and Sinkula [14] found that the concepts are empirically distinct and have independent and synergistic effects on organizational performance. However, one of the implications of their research is their call for more study of the specific nature of these effects. The purpose of this paper is to contribute to this research stream by assessing the impact of market orientation and learning orientation on capabilities. It is our position that the impact of the effects of learning and market orientation can be explained by the development of capabilities that, in turn, affect market share and profitability. Moreover, as Mascarenas, Baveja, and Jamil [15] noted, little is known about how core competencies arise in organizations. Thus, this paper will lend insights into the relationship between market and learning orientation, and performance by examining a set of intervening variables.

We will address these issues in the context of metal part producers. These companies are interesting for two reasons. First, a large portion of the economy involves the production of goods that are used in the assembly of final products. These companies often use their technical and engineering capabilities as their bases of competition, and often pay less attention to marketing issues [16]. Thus, we expect these firms to demonstrate differences in learning and market orientation and serve as an interesting sample. Second, with the increasing consolidation in the supply base and emerging pressure to develop an information technology infrastructure to support transactions and customer service, adaptation pressures are significant and may require substantial business process reconfiguration.

LITERATURE REVIEW

The following sections discuss organizational capabilities, market orientation and learning orientation and includes a series of hypotheses developed from extant literature.

Organizational Capabilities

Capabilities have attracted the interest of researchers and managers because of their impact on the firm s ability to identify sources of sustainable competitive advantage. Grant [17] defines capabilities as complex patterns of coordination between people and between people and resources that are learned through repetition. Considering the population of interest (metal processors in the middle of the value stream), we identified categories of capabilities using multiple sources.

First, we considered the capabilities required for winning and fulfilling contracts, criteria suggested by Birchall and Tovstiga [18]. Their business process value chain included marketing, sales, engineering, operation, and administration. We adapted these categories by combining **marketing and sales** (since these are often a single function for many of the smaller firms in the sample). We then divided engineering into **product/service capabilities** (which includes product quality and after sale service) and **technical capabilities** (which includes metallurgy and R&D capabilities). This division accommodates process and development engineering, related but distinct skills in industries that make custom engineered parts. We also replaced operations with **order fulfillment** to focus on delivery lead time and volume flexibility — two critical areas for customers requiring just in time inventory for sometimes erratic production schedules, and renamed administration to **upper management capabilities** to reflect the strategic insight of the firm s leaders.

In addition to Birchall and Tovstiga s classification, we included new categories of capabilities to reflect the pressures in the supply chain. First, given the growing importance of information technology, we included **information systems** as a capability. This is consistent with Moore [19] who argued that information technology should be seen as a line, not a staff function. Moreover, the growth in business-to-business electronic marketing [20, 21] makes information systems a critical skill area. Second, previous research indicated the growing importance of global capabilities for metal producers as their customers increase their requirements for global sourcing [22]. Thus, we included **globalization** as a capability. Finally, following Liedtka [23], we included **external partnering**, the ability to develop and maintain external partnerships as a meta-capability that affects the organization s ability to develop new capabilities. Since the firms in the study typically develop parts in collaboration with the customer firm, partnering is a critical skill to ensure that the seller is creating value for the buyer.

Market Orientation

While the literature offers several conceptualizations of market orientation, most interpretations focus on three components: 1) a customer focus, 2) a competitor focus, and 3) interfunctional coordination. For example, Naver and Slater [5], Kohli and Jaworski [7], and Day [24] focus on customer and competitor-oriented activities with emphasis on information management (i.e., acquisition, dissemination, and responsiveness) that serves to coordinate organizational behavior. Market orientation has been found to be positively related to organizational performance [6, 14, 25].

Similarly, Baker and Sinkula [14] view market orientation as a driver of organizational market information processing activity as well as how it is used in the firm s strategy. They note that while learning may occur as a result of market oriented processes, it is not necessarily an outcome of such processes. In fact, market oriented success could breed resistance to learning and change as when successful outcomes associated with past behavior and their interpretations, spawn complacency and avoidance or rejection of contrary information which may be indicative of the need for change [26]. Thus, while market oriented firms, by definition, engage in acquiring, sharing, and acting on market intelligence, they may be involved in the biased information processing of deficient information [14].

As noted by Baker and Sinkula [14] market orientation exists on a continuum qualified by the degree to which firms obtain and react to feedback from customers and competitors — the so called outside-in orientation [24]. This perspective affects the ability of the firm to work with customers to develop products, develop appropriate selling propositions and service, and develop global marketing capabilities that make the firm an attractive supplier vis-à-vis its competition. As such, we formally propose the following hypotheses.

H_1: Marketing capabilities will be rated stronger for firms higher on market orientation than for firms lower on market orientation.

H_2: Product/service capabilities will be rated stronger for firms higher on market orientation than for firms lower on market orientation.

H_3: Global capabilities will be rated stronger for firms higher on market orientation than for firms lower on market orientation.

Baker and Sinkula [14] posited and found support for a positive relationship between a firm s market orientation and its new product success. Moreover, Clark and Wheelwright [26] argued that effective engineering solutions require the use of deep understanding and insight about the customer — a key characteristic of market orientation. By extension, we propose a likely market orientation-technical capabilities relationship. Specifically:

H_4: Technical capabilities will be rated stronger for firms higher on market orientation than for firms lower on market orientation.

Effective communication and information management is at the heart of market orientation [5, 6]. Further, market orientation influences the scope of market information processing activity and prioritizes its use in the strategic process [14]. It follows that:

H_5: Information systems capabilities will be rated stronger for firms higher on market orientation than for firms lower on market orientation.

Lastly, Kohli and Jaworski [7] and Webster [27] recognize the significance of confluence between top management beliefs, attitudes, and commitment and a company s market orientation. Therefore, we propose that:

H_6: Upper management capabilities will be rated stronger for firms higher on market orientation than for firms lower on market orientation.

Note that we do not expect higher versus lower market oriented firms to evidence significant differences for order fulfillment and external partnering capabilities. Based on our review of relevant literature, we believe learning orientation to be more strongly implicated in capabilities tied to real-time change and external relationships. Our reasoning is explained in the following section.

Learning Orientation

A learning orientation is characteristic of a firm associated with higher order learning, i.e., generative, double loop, proactive learning that changes firm norms which is typically required for major strategic reorientation [14]. In contrast, most organizational learning is single loop, adaptive learning. That is, reactive responses to environmental events likely to relate to tactical adjustments [9, 25].

A learning orientation is associated with such values as: 1) commitment to learning, 2) openmindedness, and 3) shared vision [14]. These values contribute to an organizational culture whereby individuals feel the need to understand cause and effect relationships, surface and question long-standing assumptions, beliefs, and routines, and share a sense of purpose and direction that motivates learning [28 - 31]. Moreover, learning orientation is positively related to organizational performance variables [14].

In summary, Baker and Sinkula [14] note that, while related, market and learning orientation are distinct concepts each with potentially distinct as well as synergistic effects on organizational processes. Thus, market orientation is reflected by a firms knowledge-producing behaviors and is thereby implicated in its market information processing activity which may routinely result in adaptive (single-loop) learning. In contrast, learning orientation is reflected by a firms knowledge-questioning values and is thereby implicated in its propensity for generative, double-loop learning which encompasses more than a purely marketplace focus.

While we expect firms higher on market orientation to be rated significantly stronger on product/service, marketing, technical, information system, and upper management capabilities, we also expect these same effects for firms higher on learning orientation compared to firms lower on learning orientation. Baker and Sinkula [14] implicate learning orientation in the market information processing activities of firms. Thus, while market orientation impacts the scope of such activity, learning orientation influences the higher order examination of this activity (e.g., challenging assumptions regarding information accuracy and interpretation). Whitten, Bentley, and Ditten [34] argue that analyzing problems and understanding data requirements are critical for effective information system implementation. Baker and Sinkula [14] also note the likely impact of market information processing activities on the quality of market-oriented responses. Morgan, Hunt, and Mason [33] found a positive relationship between market knowledge and marketing capabilities. Based on the foregoing, we formally propose the following hypotheses.

H_7: Information system capabilities will be rated stronger for firms higher on learning orientation than for firms lower on learning orientation.

H_8: Marketing capabilities will be rated stronger for firms higher on learning orientation than for firms lower on learning orientation.

Baker and Sinkula [14] further recognize the involvement of learning orientation (along with marketing orientation) in optimizing customer spanning activities (e.g., customer service). In addition, they also posit and find support for a positive relationship between a learning orientation and a firm s new product success. Lastly, Baker and Sinkula [14] point to the potential significance of a learning orientation/top management relationship in their emphasis on a shared vision that provides the firm with a sense of purpose and direction. Thus, it follows that:

H_9: Product/service capabilities will be rated stronger for firms higher on learning orientation than for firms lower on learning orientation.

H_{10}: Technical capabilities (including R & D) will be rated stronger for firms higher on learning orientation than for firms lower on learning orientation.

H_{11}: Upper management capabilities will be rated stronger for firms higher on learning orientation than for firms lower on learning orientation.

In contrast to the above capability dimensions where we view overlap between market and learning orientation effects, we expect learning orientation to be more strongly implicated in capabilities tied to real-time change and external relationships. As noted by Baker and Sinkula [14], learning orientation (i.e., generative, double-loop learning) is likely to be directly associated with discontinuous learning. Along similar reasoning, the openmindedness [30] and so called inside-out orientation [24] of a learning oriented firm is likely to facilitate the exploration of external partnering opportunities as part of enhancing competencies to achieve competitive advantage. Note, that the development of such competencies is more inclusive than a purely market-based focus. Finally, given that a learning oriented firm is more likely to be aware of and more willing to alter decision rules and assumptions in response to changing information [14] we expect such firms to be more receptive and adaptive to real-time change requests from customers. Therefore:

H_{12}: External partnering capabilities will be rated stronger for firms higher on learning orientation than for firms lower on learning orientation.

H_{13}: Order fulfillment capabilities (relating to changes) will be rated stronger for firms higher on learning orientation than for firms lower on learning orientation.

Note that we do not expect higher versus lower learning oriented firms to evidence significant differences for global capabilities. Based on our review of relevant literature, we believe market orientation to be more strongly implicated in capabilities more closely tied to market development and expansion (i.e., global capabilities in comparison to external partnering).

Interaction Effects for Market and Learning Orientation

Baker and Sinkula [14] posited synergistic effects of learning and market orientation on organization performance. First, recall that both orientations are posited to influence market information processing activity with market orientation influencing the scope of activity while learning orientation challenges the very nature of the activity (e.g., assumptions regarding the market and the organization s relationship to the market). Further, Baker and Sinkula [14] predicted that market orientation, with its focus on gathering and disseminating market information, and learning orientation, with its emphasis on examining underlying logics and models which impact interpretation of information, combine to enhance market-oriented behaviors. As they recognize, such a view is consistent with Day s [24] conception of synergy arising from combined inside-out and outside-in process perspectives. Baker and Sinkula [14] found some support for interactive (synergistic) effects for market and learning orientation on market share relative to a firm s largest competitor but not for overall performance. Thus, by extension, the most relevant capability dimensions to the above reasoning appear to be information system (i.e., tied to market information processing activity synergies) and product/ service and marketing (i.e., tied to the enhancement of market-oriented behaviors) capabilities. Therefore, we propose that:

H_{14}: Information system capabilities will be rated strongest for firms higher on market and learning orientations than for other firms.

H_{15}: Product /service capabilities will be rated strongest for firms higher on market and learning orientations than for other firms.

H_{16}: Marketing capabilities will be rated strongest for firms higher on market and learning orientation than for other firms.

Finally, with respect to the new product success performance variable, Baker and Sinkula [14] argue that new product development can occur at a strong rate for either a high market orientation (by reacting to customer needs and competitor offerings) or a high learning orientation (through innovative disruptions of the status quo, that is, thinking outside the box) environment. As a consequence, they do not expect strong synergy between orientations for this variable and as such none is proposed here. Based on our review of relevant literature, we have not identified any other potential market and learning orientation interaction effects on identified capabilities.

METHODOLOGY

Sample

This study involved a sample of metal part producers from three separate metal forming technologies: powder metallurgy, casting, and heat treating. Although distinct, these technologies all deal with the mid-point of the supply chain (i.e., they manufacture component parts from raw materials and sell them to OEMs or higher tier suppliers) and deal with a common set of problems.

We started with three different industry lists; the directory of powder metallurgy part producers maintained a by leading industry consultant [34]; the industry directory maintained by of the Aluminum Casting Research Laboratory at Worcester Polytechnic Institute, and the membership of the Center for Heat Treating Excellence. Using these lists, we eliminated suppliers or firms that engage in specialized markets. This resulted in a total of 247 firms (72 in heat treating, 81 in casting, and 94 in powder metallurgy).

Procedure

Following the Dillman Total Design Method [35], a preliminary letter was sent to each respondent outlining the project, explaining its importance to them, and the importance of their participation. One week later, each subject received a cover letter, survey, and a postage paid return envelope. Participants were promised a summary of results if they participated in the study. One week later a reminder post card was sent, and a follow-up survey package was sent to each non-respondent three weeks later. Data collection was terminated after another four weeks. The response rates are summarized in Table 1.

Questionnaire

Measures employed in the questionnaire consisted of scales developed specifically for constructs relevant to this research based on literature reviews and knowledge of metal part producer industries. An initial base of items were extracted from a list of supply chain capabilities developed by Laseter [36] and Aaker s [37] set of distinctive competencies identified by business unit managers. Additional items were developed specifically for the study given the capabilities identified above. Industry representatives not included in the study reviewed an initial draft of the questionnaire.

The final questionnaire included measures of managerial perceptions of firm performance on various capabilities, managerial perceptions on aspects related to market and learning orientations, and demographic descriptors.

Independent Variable Measures

As a means of differentiating higher and lower market and learning orientation firms the following measures were used. Market orientation was operationalized via six items asking respondents their views regarding their company s ability to deliver value to customers, use of customer information, orientation to customer needs, use of competitor information, ability to anticipate competitor responses, and coordination of internal activities. All items utilized seven-point scales (Cronbach s alpha = .73). Such aspects of market orientation are quite consistent with current conceptions that include customer and competitor focus and interfunctional coordination [5, 7, 24].

Learning orientation was assessed via two items related to respondent perceptions of their company s overall ability to learn and change. Again, these items used seven-point scales (Cronbach s alpha = .82) and are conceptually consistent with notions of organizational commitment to learning [28 - 31].

A median-split approach was used to partition firms into relatively low and high scoring groups on the summed market and learning orientation items. Specifically, scores of greater than 30 on the six item market orientation scale (Mean low score = 27.3; Mean high score = 34.7; $t = 15.98$, $p < .000$) and scores of greater than ten on the two item learning orientation scale (Mean low score = 8.6; Mean high score = 11.9; $t = 13.98$, $p < .000$) defined group classification.

Dependent Variable Measures

Perceptions of firm capabilities, both micro-capabilities, consisting of industry specific knowledge and skills, as well as meta-capabilities, consisting of capabitity-building competencies, were used as dependent variables in the study. The competitive advantage literature has recognized both forms of capability domain [23]. Based on a review of relevant supply chain literature in concert with researcher knowledge of the industries, 35 items related to potential industry specific or micro-capabilities were included on the questionnaire. Items related to such areas as production and service, upper management, human resource, technical/engineering, marketing, and global capabilities. One meta-capability, related to developing and maintaining external partnerships, was also included as it was viewed as potentially relevant to firms in these industries. Respondents evaluated their company s performance on each of the capability items on seven-point scales (much worse than/much better than competitors).

Given a total of 35 items related to industry specific capabilities, many with high correlations among them, a principal components analysis using varimax rotation was employed as a means of identifying a smaller number of dimensions for use in developing specific hypotheses and subsequent analysis. Using guidelines related to eigenvalue, screeplot, and interpretability criteria resulted in a seven factor solution which accounted for 61% of the total variance. Items loading not less than .6 on a primary dimension and not more than .4 on any other dimension were retained.

Items and factor loadings are presented in Table 2. The dimensions are briefly profiled below.

Factor 1, **Global capabilities**, consisted of 5 items relating to marketing, manufacturing, supply, and service (Cronbach s alpha = .92).

Factor 2, **Upper management capabilities**, included 3 items relating to leadership, vision, and planning (Cronbach s alpha = .86).

Factor 3, **Product/service capabilities,** included 4 items relating to product quality, service, and delivery (Cronbach s alpha = .74).

Factor 4, **Marketing capabilities**, consisted of 3 items relating to the sales force, promotion, and account selection (Cronbach s alpha = .68).

Factor 5, **Technical capabilities,** consisted of 2 items relating to metallurgy and research and development (Cronbach s alpha = .68).

Factor 6, **Information systems capabilities**, included 2 items relating to electronic data interchange and financial and operational reporting (Cronbach s alpha = .71).

Factor 7, **Order fulfillment capabilities**, included 2 items relating to flexibility for volume and mix changes and delivery lead time (Cronbach s alpha = .57).

As noted previously, the meta-capability domain, **External partnering**, consisting of 2 items relating to developing and maintaining external relationships was also included (Cronbach s alpha = .93). All multi-item dependent variable measures were summed and averaged.

ANALYSIS and RESULTS

Multivariate analysis of variance was used to test for differences on capability dimensions between higher and lower market and learning orientation firms. Recall, we expected both main as well as interaction effects for market and learning orientations. As expected, multivariate test statistics indicated significant main effects for market orientation (Pillai s Trace = .255; Wilk s Lambda = .745; F = 4.755, p < .000) and learning orientation (Pillai s Trace = .249; Wilk s Lambda = .751; F = 4.605, p < .000).

However, the market by learning orientation interaction was not significant (Pillai s Trace = .018; Wilk s Lambda = .982; F = .259, p < .978).

Univariate test statistics allow for a more detailed examination of expected differences on capabilities for firms higher and lower on market and learning orientations. Table 3 presents group means, F statistics, and significance levels for each capability dimension for higher and lower market orientation firms. Hypotheses 1, 2, 3, and 6 were supported by the data. Firms with higher market orientation rated their marketing, product/service, global, and upper management capabilities stronger relative to competition than firms with lower market orientation. Although the ratings for technical capabilities and information systems were in the expected direction, these were not significant. Thus hypotheses 4 and 5 were not supported.

With respect to learning orientation, of the seven capability dimensions on which we predicted significant differences, six of seven are significantly different with all in the expected direction. These results are summarized in Table 4. Firms higher in learning orientation rated their information systems, marketing, product/service, upper management, external relationship, and order fulfillment capabilities stronger relative to competition than low learning orientation firms. Thus Hypotheses 7, 8, 9, 11, 12, and 13 were supported. Although differences in technical capabilities were in the expected direction, these results were not significant. Thus, hypothesis 10 was not supported. As noted above, none of the expected interaction effects were observed. Thus, hypotheses 14, 15, and 16 were not supported.

DISCUSSION

The present study extends prior research in the area by exploring the effects of market and learning orientation on industrial firm capabilities — the sources of competitive advantage. To this end, hypotheses relating to the independent effects of market and learning orientation on specific capability domains have received support. Second, these findings have implications for managing the development of organizational capability portfolios. Third, the findings hold implications for future research in the area.

As mentioned previously, both of these orientations have been linked to company performance, however, Baker and Sinkula [14] note the need to examine the specific nature of the effects through an exploration of intervening variables. This research adds to our understanding of the dynamics of market and learning orientation by identifying perceived differences in capabilities for higher and lower market and learning orientation firms. Summarizing significant findings for the industries studied, higher market oriented firms evidenced a stronger portfolio of capabilities consisting of global, upper management, product/service, and marketing competencies compared to lower market oriented firms. Higher learning oriented firms evidenced a stronger portfolio of capabilities consisting of upper management, product/service, marketing, information systems, order fulfillment, and external partnering competencies compared to lower learning oriented firms.

Thus, higher market and learning orientations relate to overlapping yet distinct capability portfolios. Consistent with extant literature, both orientations appear to be related to customer interface behaviors as higher orientations were associated with the perceptions of stronger product/service and marketing capabilities. Further, related literature also notes a prominent relationship between the orientations and top management and, not surprisingly, we noted high market and learning oriented firms to be perceived as having stronger upper management capabilities.

Of interest were observed findings with respect to distinct differences for high market versus high learning orientations. High market oriented firms also evidenced stronger perceived global capabilities which relate to external market development competencies. In contrast, high learning oriented firms evidenced stronger perceived information system, order fulfillment and external partnering capabilities which relate to internal adaptability and external learning competencies. Given capabilities are linked to performance and competitive advantage, results of this research hold implications for organizational development.

Managerial Implications

Clearly, what emerges from this research is that market and learning orientations provide for some overlap in capabilities but also for some unique differences in the overall portfolio of firm capabilities. For metal part producer firms, enhancing market-oriented behaviors (i.e., customer and competitor information gathering and dissemination) is likely to enhance market-oriented (i.e., product/service, marketing, and global) competencies.

In contrast, orienting a firm s culture toward learning (i.e., strengthening learning-oriented values) is likely to enhance market-oriented (i.e., product/service and marketing) and learning-related (i.e., information systems, order fulfillment, and external partnering) competencies. The decision to enhance both market and learning orientations is likely to result in the most complete portfolio of capabilities. Although as noted in Baker and Sinkula [14], market-oriented behaviors are more readily changed than learning-oriented values. A market or learning orientation alone, while generating benefits for the firm, could result in critical gaps in capabilities.

Research Implications

Our research should be viewed from the perspective of a cross-sectional study employing self-report managerial perceptions of measured constructs in a metal part producer industry. Although Day and Nedungadi [28] note the appropriateness of examining managerial representations of competitive advantage, future research should assess the generalizability of findings of the present study in alternative industries and/or at different points in the supply chain. For instance, do different dynamics associated with other industries alter the effects observed in the present study? Further, are there different capabilities in addition to those identified in the present study whose strength may be related to higher market and/or higher learning orientation?

Beyond identified effects, replications and extensions of the present research should consider proposed effects between market and learning orientation and organizational capabilities that were not found to be significant. Specifically, no effects were found for either orientation on technical (metallurgy and R & D) capabilities. Perhaps in this industry, technical capabilities, as defined, are a necessary but not sufficient competency domain for competitive advantage.

It was also expected that a higher market orientation would be associated with stronger perceived capabilities related to information systems. Perhaps the expected result was not observed due to the operationalization of information systems as consisting of electronic data interchange and financial and operational reporting. These particular systems could be viewed as a closer reflection of inside-out (learning oriented) rather than outside-in (customer/competitor information gathering) processes.

In addition, the lack of market and learning orientation interaction effects begs further exploration. While interaction effects have been found in related research, they have been observed for firm performance variables and not for firm capability variables. Is this attributable to differences in these dependent variable domains or to industry differences as noted above?

Finally, relationships among market and learning orientations, firm capabilities, and performance outcomes should be addressed. Specifically, what are the effects of market and learning orientation (independently and combined) on various capability portfolios? Considering our results, with those of Morgan, Voorhees, and Mason [33] that suggest relationships between marketing capabilities and firm performance, the development of a chain of orientation, capabilities, and outcomes would be a contribution to the literature. Also, an exploration of which types and combinations of capabilities are most influential on the various performance indicators (i.e., sales growth, new product success, market share, and overall performance) would be of interest.

Future research could also integrate organizational-level domains with individual-level perspectives. For example, Celuch, Kasouf, and Strieter [39] examined the influence of firm market orientation on employee efficacy and benefit perceptions related to using customer information. By extension, what are the effects of firm market and learning orientations on other salient employee market-oriented cognitions and behavior?

In conclusion, understanding the effects of market and learning orientations will continue to be a significant topic within the marketing strategy discipline. It is hoped that the present research which links market and learning orientations to specific organizational capabilities will contribute to future empirical efforts aimed at increasing understanding of the dynamics of competitive advantage.

TABLE 1

Sample and response rates by industry.

Industry	**Sample**	**Response**
Heat treating	72	44 (61.1%)
Metal casting	81	41 (50.6%)
Powder metallurgy	94	44 (46.8%)
Total	**247**	**126/247 (51%)**

TABLE 2

Capabilities and factor loadings.

	Factors						
Item	1	2	3	4	5	6	7
Global marketing	.84						
Global manufacturing	.87						
Global Supply	.91						
Global Service	.85						
Exchange rate fluctuation	.76						
Leadership		.80					
Shared vision		.85					
Strategic planning		.80					
Product quality			.72				
After-sale service			.62				
Delivery history			.64				
References			.68				
Sales force				.61			
Promotion				.66			
Account selection				.74			
Metallurgy					.69		
Research & development					.80		
Information systems & electronic data interchange						.75	
Financial & operational reporting						.69	
Delivery lead time							.70
Flexibility for volume & mix Changes							.69

Note: Respondents were asked to evaluate their company s performance on capabilities on a 1(Much worse than competitors) to 7 (Much better than competitors) scale.

TABLE 3

Group means, F statistics, and significance levels for capability variables for higher and lower market orientation firms.

H_0	Dependent variable	Group means		F	p	Conclusion
		High market orientation	Low market orientation			
H_1	Marketing capabilities	4.06	4.71	9.99	.002	Supported
H_2	Product/service capabilities	5.06	5.69	16.28	.000	Supported
H_3	Global capabilities	3.36	4.08	7.59	.007	Supported
H_4	Technical capabilities	4.68	5.15	2.82	.096	Not supported
H_5	Information systems capabilities	4.51	4.99	2.39	.125	Not supported
H_6	Upper management capabilities	4.69	5.60	15.11	.000	Supported

TABLE 4

Group means, F statistics, and significance levels for capability variables for higher and lower learning orientation firms.

H_0	Dependent variable	Group means		F	p	Conclusion
		High learning orientation	Low learning orientation			
H_7	Information systems capabilities	4.47	5.08	4.84	.030	Supported
H_8	Marketing capabilities	4.14	4.67	4.11	.045	Supported
H_9	Product service capabilities	5.15	5.64	6.15	.025	Supported
H_{10}	Technical capabilities	4.71	5.17	2.37	.126	Not supported
H_{11}	Upper management capabilities	4.68	5.70	22.85	.000	Supported
H_{12}	External relationship capabilities	4.23	5.18	13.38	.000	Supported
H_{13}	Order fulfillment capabilities	4.98	5.55	10.72	.001	Supported

1. Cravens, David W.; Greenly, Gordon; Piercy, Nigel F.; and Slater, Stanley F.: Mapping the path to market leadership: Effectively combining various dimensions of strategy into an integrated process of strategic analysis and action maps the path to market leadership. *Marketing Management* **7,** 28-39 (1998).

2. Drucker, Peter F.: *The Practice of Management*. Harper, New York, 1954.

3. Keith, Robert J.: The Marketing Revolution. *Journal of Marketing* **24**, 35-38 (1960).

4. Kotler, Philip: *Marketing Management*. (5th ed.), Prentice Hall, New York, 1984.

5. Narver, John C. and Slater, Stanley F.: The Effect of a Business Orientation on Market Profitability. *Journal of Marketing* **54,** 20-35 (1990).

6. Jaworski, Bernard J and Kohli, Ajai K.: Market Orientation: Antecedents and Consequences. *Journal of Marketing* **57**, 53-70 (1993).

7. Kohli, Ajai and Jaworski, Bernard J.: Market Orientation: The Construct, Research Implications, and Managerial Consequences. *Journal of Marketing* **54**, 1-18 (1990).

8. Balakrishnan, Subra: Benefits of Customer and Competitive Orientations in Industrial Markets. *Industrial Marketing Management* **25**, 257-269 (1996).

9. Argyris, Chris and Donald A. Schon: *Organizational Learning: A Theory of Action Perspective*. Addison-Wesley, Reading, MA, 1978.

10. Fiol, C. Marlene and Lyles, Marjorie A.: Organizational Learning. *Academy of Management Review* **10**, 803-813 (1985).

11. Slater, Stanley F. and Narver, John C.: Market Orientation and the Learning Organization. *Journal of Marketing* **59**, 63-74 (1995).

12. De Geus, Arie P: Planning as Learning. *Harvard Business Review* **66,** 70-74 (1988).

13. Christensen, Clayton M.: *The Innovator s Dilemma*, HBS Press, Boston 1997.

14. Baker, William E. and Sinkula, James M.: The synergistic effect of market orientation and learning orientation on organizational performance. *Journal of the Academy of Marketing Science* **27**, 411-427 (1999).

15. Mascarenhas, Briance, Baveja, Alok, and Mamnoon, Jamil: Dynamics of Core Competencies in Leading Multinational Companies. *California Management Review* **40**, 117-132 (1998).

16. Avlonitis, George J. and Gounaris, Spiros P.: Marketing Orientation and Company Performance: Industrial vs. Consumer Goods Companies. *Industrial Marketing Management* **26**, 385-402 (1997).

17. Grant, Robert: The Resource-Based Theory of Competitive Advantage: Implications for Strategy Formulation. *California Management Review* **Spring,** 114-135 (1991).

18. Birchall, David W. and George Tovstiga: The Strategic Potential of a Firm's Knowledge Portfolio. *Journal of General Management* **25,** 1-16 (1999).

19. Moore, Geoffrey A.: *Living on the Fault Line: Managing Shareholder Value in the Age of the Internet*. Harper Business, New York, 2000.

20. Brunelli, Mark A.: B2B E-commerce will Hit $7.29 Trillion by 2004. *Purchasing*, **March 25**, S18 (2000).

21. Halford, Joshua: B-2-B Buying Picks Up Speed. *Industry Standard* (online ed.), http://www.thestandard.com/research/metrics/display/0,2799,18974,00.html, October 2 (2000).

22. Kasouf, Chickery J., David C. Zenger, P. Ulf Gummeson, and Diran Apelian: *The P/M Delphi Study: A Final Report.* Metal Powder Industries Federation, Princeton, NJ (1994).

23. Liedtka, Jeanne M.: Collaborating Across Lines of Business for Competitive Advantage. *Academy of Management Executive* **10**, 20-37 (1996).

24. Day, George: The Capabilities of Market-Driven Organizations. *Journal of Marketing* **58,** 37-52 (1994).

25. Sinkula, James M. Market Information Processing and Organizational Learning. *Journal of Marketing* **58**, 35-45 (1994).

26. Clark, Kim B. and Whelwright, Steven C.: *Managing New Product and Process Development.* Free Press, New York, 1993.

27. Webster, Frederick E.: Rediscovering the Marketing Concept. *Business Horizons* **31,** 29-39 (1988).

28. Shaw, Robert B. and Dennis N. T. Perkins: Teaching Organizations to Learn. *Organization Development Journal* **9**, 1-12 (1991).

29. Porac, Joseph F and Howard Thomas: Taxonomic Mental Models in Competitor Definition. *Academy of Management Review* **15**, 224-240 (1991).

30. Senge, Peter M., *The Fifth Discipline.* Currency Doubleday, New York, 1990.

31. Day, George S.: Learning About Markets. *Marketing Science Institute Report Number 91-117.* Marketing Science Institute, Cambridge, MA (1991).

32. Whitten, Jeffrey L., Bentley, Lonnie D., and Dittman, Kevin C.: *Systems Analysis and Design Methods* (5th ed.). McGraw-Hill Irwin, Boston, 2000.

33. Morgan, Neil, Voorhees, Douglas, and Mason, Charlotte: The Impact of Marketing Capabilities and Market Knowledge on Business Performance. *2001 American Marketing Association Winter Educators Conference* (forthcoming).

34. Pease, Leander: *P/M Part Producers*. Powder Tech Associates, North Andover, MA, 1999.

35. Dillman, Don A.: *Mail and Telephone Surveys: The Total Design Method*. Wiley, New York, 1978.

36. Laseter, Timothy M.: *Balanced Sourcing: Cooperation and Competition in Supplier Relationships*. Josey Bass, San Francisco, 1998.

37. Aaker, David A.: Managing Assets and Skills: The Key to a Sustainable Competitive Advantage. *California Management Review* **31,** 91-105 (1989).

38. Day, George S. and Nedungadi, Prakesh: Managerial Representation of Competitive Advantage. *Journal of Marketing* **58**, 31-44 (1994).

39. Celuch, Kevin G., Kasouf, Chickery J., and Strieter, Jeffrey C.: The Influence of Organizational Market Orientation on Individual-Level Market Oriented Cognitions. *Psychology and Marketing* (forthcoming).

THE EFFECTS OF MARKET AND LEARNING ORIENTATION ON ORGANIZATIONAL CAPABILITIES

This study extends prior research by exploring the effects of market and learning orientation on industrial firm capabilities — the sources of competitive advantage. Extant research has found these concepts to be empirically distinct and to have independent and synergistic effects on organizational performance indicators. The present study generally supports hypotheses relating to independent effects of market and learning orientation on specific capability domains. Findings hold implications for managing the development of organizational capability portfolios as well as for future research aimed at understanding competitive advantage dynamics.

Environmental Trends for the U.S. Powder Metallurgy Industry

Adriana Diaz-Triana
Civil and Environmental Engineering Department
Northeastern University.

Jacqueline A. Isaacs
Assistant Professor
Mechanical, Industrial and Manufacturing Engineering
Northeastern University

Abstract

Environmental issues are becoming increasingly important as U.S. Environmental Protection Agency (EPA) regulations become more stringent with regard to emissions in manufacturing. Although there are no comprehensive studies published, powder metallurgical (P/M) processes have generally been touted as environmentally benign and P/M has become a competitive method of production for near net shape parts. Although the nature of the P/M manufacturing processes differs from other metal processing, P/M processing is routinely categorized with the larger metal processing industry sector. Environmental data to assess the P/M industry is not readily extracted from other metal sectors.

To comprehensively improve the environmental aspects of P/M processing, knowledge of several interrelated topics is required. For the purposes of this study, the key topics include: a general description of the P/M industry, a description of process emissions and an understanding of the U.S. Federal statutory and regulatory framework. This study assesses published information gathered from a variety of sources, such as the U.S. Environmental Protection Agency, U.S. Bureau of the Census, Metal Powder Industries Federation as well as technical papers and various business statistical databases.

In this study, a preliminary evaluation of the U.S. EPA Toxics Release Inventory (EPA-TRI) data reveals a more complete, accurate, and up-to-date environmental profile of the P/M industry.

Approaches to enhance the environmental evaluation of the P/M industry, as well as the assessment and modeling for cost of pollution reduction are outlined as part of future work. The identification of technical options to reduce wastes and emissions in the P/M manufacturing cycle, alternative management practices, and changing incentives will be the expected outcomes of this work.

Table of Contents

1. Introduction

2. Strategy for environmental assessment study

3. Powder metallurgy: an overview

4. U.S. P/M industry size and economics

5. Environmental regulations for the P/M industry

    5.1 Resource Conservation and Recovery Act (RCRA)

    5.2 Clean Water Act (CWA)

    5.3 Clean Air Act (CAA)

    5.4 Emergency Planning and Community Right-to-know Act (EPCRA)

6. Emissions and releases from P/M processes

7. Toxics Release Inventory for the P/M industry

8. Procedure to estimate releases

9. TRI trends for the P/M industry
    9.1 General trends
    9.2 Specific releases from P/M facilities
    9.3 Specific sectors: comparison of powder production and part production
        9.3-a Trends for powder producers
        9.3-b Trends for parts producers
    9.4 Summary of trends and discussion of emission sources

10. Complementary approaches to measure environmental trends

    10.1 Toxicity indices approach
    10.2 Production baseline for normalization of releases

11. Future work

12. References

List of Tables

Table 1: North American metal powder shipments between 1997 and 1999

Table 2: Hazardous wastes relevant to the P/M industry, regulated under RCRA [6]

Table 3: SIC code distribution among facilities studied

Table 4: Summary of chemical releases and transfers for the P/M industry

Table 5: Volatile Organic Compounds in air releases for the P/M industry

Table 6: Metal compounds in metal air releases and metal transfers off-site for the P/M industry

Table 7: Air emissions, transfers off-site and total releases for powder producers and part producers during 1993 and 1998

List of Figures

Figure 1: P/M industry releases for 1993 and 1998

Figure 2: Chemicals in air releases in 1998

Figure 3: Chemicals in transfers off-site in 1998

Figure 4: Average emissions and total releases per facility for part and powder manufacturers in 1993 and 1998

Figure 5: Chemical compounds in air releases for powder producers, during 1993 and 1998

Figure 6: Chemical compounds in air releases for part producers in 1993 and 1998

Figure 7: Threshold Limit Values (TLV-TWA) for metals in P/M industry [25]

Figure 8: Threshold Limit Values (TLV-TWA) for inorganic and organic compounds in P/M industry [25]

1. Introduction

Traditionally, design and process planning have focused on improving the functionality of the product from a design perspective, and on increasing the production rate and quality from a manufacturing point of view. There has been an emerging focus on cleaner manufacturing processes due to stricter regulatory mechanisms regarding industrial releases. At the same time, there is an increasing driving force of consumers that demand “green” products, and for companies that perform with environmental stewardship. These aspects reinforce a need to evaluate and minimize the environmental impact of manufacturing processes.

Over the last decade many U.S. industries have become increasingly cleaner and more competitive, by choosing source reduction technologies over end-of-pipe abatement and avoiding the generation and release of millions of pounds of multimedia wastes, which in many instances results in financial benefit. The waste reduction strategy reflects a commitment of the companies to both the health of the general public and the quality of the environment [1].

As the powder metallurgy industry in the United States grows and evolves, environmental and economic considerations are becoming increasingly important. Few overviews or detailed studies have been done on the environmental performance of the U.S. P/M industry to provide a basic framework for instituting and managing successful pollution control, material and energy conservation programs in this industrial sector.

The two main areas of ongoing research discussed in this work include: i) environmental trends in the P/M industry and ii) cost assessment of alternatives for pollution reduction in the P/M industry.

Environmental Trends

The focus of this part of the study tracks trends in waste and emissions generation from the P/M sector over a recent five-year period. An analysis of U.S. Environmental Protection Agency’s Toxics Release Inventory (EPA-TRI) for the P/M industry involves collection of data for waste media (liquid, solid and gases) that have different fate and transport mechanisms in the environment, and chemical exposure to humans. A preliminary quantitative comparison of P/M industry releases over time is presented for two defined sub-sectors: powder production and parts production. Identification of wastes and emissions, in terms of their chemical composition and likely medium of transfer are of importance here.

Two methodologies are proposed to assess the TRI data further, for a more complete evaluation for environmental performance of the P/M industry. The first methodology incorporates toxicological information of the chemicals released, with the goal to evaluate the potential impact on human health.

The second methodology incorporates selected production data from the P/M industry with the TRI data. This methodology allows comparison for tracking environmental and economic performance with respect to industry growth.

Cost Assessment for Pollution Reduction

Pollution control can be achieved by standard end-of-pipe approaches, intended to meet regulatory specification of certain releases. It can also be achieved through source reduction with the development of new materials and the application of cleaner technologies in manufacturing. The P/M manufacturing sector needs to evaluate the incentives and tradeoffs that drive the potential investments and expected benefits, which could result in a shift from traditional environmental compliance to proactive pollution prevention at the source. By using selected case studies in the P/M sector, a cost assessment modeling tool will be developed to analyze the cost impact of alternative means for pollution control.

2. Strategy for Environmental Assessment Study

Information collection and data analysis are key factors for the study of environmental trends. Published literature reviewed in this study includes EPA databases, industry related reports, company literature, journal articles and other technical references. Interpretation of these data revealed preliminary trends for toxic wastes releases over time in the P/M industry.

Industry collaboration is of critical importance to complete the environmental performance evaluation of the P/M industrial sector. Consultation and interviewing will allow for revision of priorities and opportunities for improvement of current environmental programs in selected companies. It will also serve as a reliable and updated source of information related to production and growth of the industry.

The development, validation and use of a model to assess the cost of various pollution control alternatives (and/or waste reduction technologies) will provide important insights for business decisions in the P/M industry. Again, input from industry is necessary to understand the relation between current business strategies and environmental management strategies. Evaluation of alternatives for reduction at the source and waste minimization will be given high priority.

3. Powder Metallurgy: An Overview

Powder metallurgy is one of the most versatile manufacturing processes in existence, P/M processing has evolved as an efficient and cost-effective alternative to machined parts, castings, and forging. P/M facilitates the mass production of high quality, complex metal parts at low cost, with greater strength, durability, and performance. P/M is also the production method of choice for parts that require the use of complex materials, such as tungsten and molybdenum, which are difficult to produce through other processes [2]. P/M processes have the following advantages:

- Low cost
- Mass production of high quality, strong, complex metal parts
- Close tolerances
- Good surface finish
- Reduction of post-production operations
- Availability of wide variety of alloyed materials
- Heat treatment for increased strength or wear resistance
- Controlled porosity for self-lubrication
- Complex, unique shapes possible
- Component reliability in critical applications

From the environmental point of view, because P/M parts are formed by mixing, compacting, and sintering metal powders, the technology claims virtually no waste. Typically, more than 97% of the starting raw material is retained in the finished part [2]. P/M is the lowest energy consumer of all comparable metal working processes. Because P/M parts are produced at or very close to final dimensions, post-production machining requirements are either extremely minor or eliminated. The additional processing or assembly steps present in other metalworking processes require energy, but these steps can often be eliminated when parts are manufactured through P/M. Powder metallurgy technology has been touted as environmentally benign, producing a minimum of fumes or toxic waste.

4. U.S. P/M Industry Size and Economics

The P/M parts and products industry in North America has estimated sales of over $5 billion. The North American powder metallurgy industry has various sub-sectors: parts producers, powder producers, equipment suppliers, consultants and research companies. The parts producers sector shows companies that make conventional P/M products from iron, and copper-base powders, and companies that make specialty P/M products, such as superalloys, porous products, friction materials, strip for electronic applications, high strength permanent magnets, magnetic powder cores and ferrites, tungsten carbide cutting tools and wear parts, metal injection molded parts, and tool steels. The value of U.S. metal powder shipments (including paste and flake) was $1.737 billion in 1997 [3]. Table 1 presents data on North American metal powder shipments over a period of three years. Powder shipments for all powders have increased over this timeframe.

Powder metallurgy is now the fastest growing net-shape metal manufacturing industry in the United States. The auto market remains the P/M parts industry's top customer. Major growth markets in 2000 for P/M products are automotive, medical equipment, civilian and military ammunition, power tools and hardware, and sporting goods [3].

Table 1: North American metal powder shipments between 1997 and 1999

Product	**1997** (short tons)	**1998** (short tons)	**1999** (short tons)
Iron and steel	389,379	410,553	443,253
Stainless steel	5,246	5,875	7,157
Copper / copper-base	24,444	25,051	25,240
Aluminum	44,417	48,046	53,779
Molybdenum	2,500^E	2,500^E	2,500^E
Tungsten	1,059	1,509	1,533
Tungsten carbide	6,897	7,229	6,123
Nickel	11,536	10,873	10,333
Tin	1,037	1,075	1,016
Total	486,143	512,711	550,934

Modified from [3]; (E: Estimate)

The P/M part production sector currently includes approximately 213 companies competing at various levels in the manufacture of P/M structural parts, powder forging, bearings, friction materials and metal injection molded products. Within this sector there are three types of companies. First the job shop/specialties manufacturers, accounting for 77% of firms, generating less than $10 million per year in revenue. Second, the repetitive process manufacturers, representing 17% of the P/M parts industry, with revenues in the range of $10 million to $50 million per year. Third, the large process manufacturers, representing 5% of the firms in the P/M parts sector, produce approximately half the production for all manufactured parts [4].

Beginning in 1997 The U.S. Bureau of the Census gathered information specific to the P/M parts manufacturing, on the basis of the North American Industry Classification System (NAICS). For the P/M industry, the corresponding NAICS is 332117. This code comprises establishments "primarily engaged in manufacturing powder metallurgy products by compacting them in a shaped die and sintering" [5]. The statistical information for the P/M parts division, for the year 1997 shows 111 companies, for 1.13 billion dollars value of shipments.

The number of P/M parts manufacturing companies included in the NAICS code in 1997 (111) does not map to the number of companies (213) mentioned in the study by Apelian et al. (1998). This indicates a disparity of information and statistics from different sources, leading to some difficulty in the evaluation and analysis of trends.

5. Environmental Regulations for the P/M Industry

The major U.S statutes and regulations that apply to the Fabricated Metal industry (Where P/M is considered a subcategory) are the Resource Conservation and Recovery Act, Clean Water Act, Clean Air Act, and the Emergency Planning and Community Right-To-Know Act. These regulations are applicable to the fabricated metals industry, and therefore are applicable to the P/M industry subcategory as well.

5.1 Resource Conservation and Recovery Act (RCRA)

The Code of Federal Regulations (CFR), number 40, part 261, refers to the identification and listing of solid hazardous wastes (or combination of solid wastes). The wastes associated with the powder metal industry include sludge that may contain heavy metals such as chromium and lead. Inorganic acids and organic solvents used in cleaning and degreasing operations could be subject to RCRA, if they are spilled or disposed of prior to use. Spent solvents are also considered hazardous wastes under RCRA. The list and description of some of the hazardous wastes relevant to the P/M industry is presented in Table 2.

5.2 Clean Water Act (CWA)

The Clean Water Act regulations that affect the P/M industry correspond to the 40 CFR, Part 471 (non ferrous forming), Subpart J: “Metal Powder Subcategory”. It provides the Standards for wastewater generated by any of the following operations:

- Atomization for the production of metal powder
- Pressing
- Sizing
- Impregnation
- Grinding
- Tumbling, burnishing and cleaning

Wastewater from these operations can have a significant content of heavy metals, in the form of suspended particles or in solution, as well as lubricants and other chemical agents, depending on the manufacturing process. The Standards include daily maximums and monthly maximum average concentration limitations. The Standards are based on milligrams per square meter of operation, and determine the amount of wastewater pollutants that may be discharged to waters of the United States or introduced to publicly owned treatment works (POTW) from the process operations of the P/M subcategory [6,7].

Table 2: Hazardous wastes relevant to P/M industry, regulated under RCRA [6]

EPA Hazardous Waste Number	Description
D001	Ignitable wastes
D002	Corrosive wastes
D003	Reactive wastes
D007 (Cr); D008 (Pb); D0018, (Benzene); D0035 (Methylethyl ketone); D0039 (Tetrachloroethylene), and D040 (Dichloroethylene).	Wastes that are hazardous due to the characteristics of toxicity for each of the constituents.
F001	Halogenated solvents used in degreasing: tetrachloroethylene, methylene chloride, 1,1,1-trichloroethane, carbon tetrachloride, and chlorinated fluorocarbons.
F002	Spent halogenated solvents and solvent mixtures or blends containing, before use, one or more of the above halogenated solvents or those listed in F001, F004, F005.
F003	Spent non-halogenated solvents: xylene, acetone, ethylacetate, ethylbenzene, ethyl ether, methylisobutyl ketone, n-butyl alcohol, cyclohexanone, and methanol.
F004	Spent non-halogenated solvents: cresols and cresylic acid, and nitrobenzene; all spent solvent mixtures/blends.
F005	Spent non-halogenated solvents: toluene, methy ethyl ketone, carbon disulfide, isobutanol, pyridine, benzene, 2-ethoxyethanol, and 2-nitropropane and spent solvent mixtures or blends.

5.3 Clean Air Act (CAA)

Currently, 188 Hazardous Air Pollutants (HAP's) are regulated under Section 112 of the Clean Air Act (40 CFR 61). The U.S. EPA identified a list of priority HAP's for inclusion in an air toxics inventory. Within the proposed EPA list of priority HAP's from stationary sources are substances such as chromium and chromium compounds, lead and lead compounds, nickel and nickel compounds, manganese, and cobalt. Other non-metal substances (mainly used as cleaning solvents in the P/M industry) are included in the list: e.g., tetrachloroethylene, benzene, toluene, xylene, methanol, methylethyl ketone, trichloroethylene, and glycol ethers. The regulation affects the P/M industry because of its potential to release air emissions of substances included in the list [6].

For industrial air emissions, EPA created the National Emission Standards for Hazardous Air Pollutants for "major sources categories" (Sub-Chapter C) and "area sources". There is not a specific source category pertaining to the P/M industry, but there are some categories that relate to metal processing (e.g. mining, refining, and production of metals). These categories may be relevant to the P/M industry and include Standards for halogenated solvent cleaning, Standards for ferroalloys production: ferromanganese and silicomanganese, Standards for secondary brass and bronze products, and Standards for secondary aluminum production.

5.4 Emergency Planning and Community Right-To-Know Act (EPCRA)

The Superfund Amendments and Reauthorization Act (SARA) of 1986 created the Emergency Planning and Community Right-to-Know Act (EPCRA, also known as SARA Title III). This statute was created to improve community access to information about chemical hazards, and to facilitate the development of chemical emergency response plans by states and local governments.

EPCRA Section 313 requires manufacturing facilities included in SIC codes 20 through 39, which have ten or more employees, and which manufacture, process, or use specified chemicals in amounts greater than threshold quantities, to submit an annual toxic chemical release report. This report covers releases and transfers of toxic chemicals to various facilities and environmental media, and allows EPA to compile the National Toxics Release Inventory (TRI) database. All the information submitted pursuant to EPCRA regulations is publicly accessible, unless protected by a trade secret claim [8].

6. Emissions and Releases from P/M Processes

Because of the nature of the final product and the fabrication processes in the manufacture of metal powders, the main concern is the release of particulate matter into the atmosphere. In the atomization process for example, releases to air can occur during melting of the raw metal in the form of fumes, or during the fabrication of the powder if the gas atomization chamber is not sealed properly. Dusting and dispersion of particles into the air occur during discharge of collection systems, separation dewatering, drying, and handling of final product.

Certain powders can have harmful effects on workers exposed to them, and proper powder handling requires safety precautions and cleanliness. Particles in the range between 0.01 and 10 μm are of concern because they are associated with lung dysfunction and transport through the blood to other body organs [9].

When the finished metal powder does not have the desired particle size distribution or chemistry, or if it is contaminated, it is regarded as scrap. Scrap can be sold at a low value, but there are some cases in which it is discarded as solid waste.

Other sources of wastes in powder production are associated with cleaning operations for the equipment. Solvents and emulsions are of common use for cleaning surfaces exposed to the powder. Solvents are of wide use in many industrial applications, including powder manufacture, and they can be a source of emissions and wastes.

In the case of parts fabrication, there are various sources of emissions and wastes, corresponding to the various process steps. Admixed powders are most susceptible to dusting during mixing. Dusting refers to the dispersion and movement of fine solid particles in the air. Pre-alloyed and diffusion alloyed powders are also prone to dusting. This may happen during discharge and mixing operations. Not only can the main powder become a source of emission if handled incorrectly, also the additives to bind, lubricate, coat or agglometate-deagglomerate the powder mixture, could be released.

Lubricants are usually mixed with the metal powder before pressing, at typical concentrations between 0.5 and 1.5 % in weight, to minimize die wear and ease ejection. Lubricants based on stearic acid, containing metals such as aluminum, zinc, lithium, magnesium and calcium are commonly used [10].

Lubricants need to be removed during sintering, in a process called “delubing”. Delubing occurs when a small amount of an oxidizing agent causes the lubricant to oxidize. Hydrocarbon vapors and metals from the lubricant could be emitted into the air [11]. The potential sources of emissions during sintering are comprised in three categories:

a. Production of sintering atmospheres
b. Mass transfer mechanisms during sintering
c. Operational problems during sintering

<u>Production of sintering atmospheres:</u> The generation of sintering atmospheres requires different liquid or gaseous substances that could contribute to air emissions if they are not handled properly. Propane, ammonia, nitrogen and hydrogen in gaseous forms, usually provided by compressed hydrogen gas tubes or liquid gas tanks, have to be safely stored and administered. Methanol,

if used in liquid form, needs special care in order to avoid vaporization before its use. Other possible releases to the air are related to fugitive emissions of gases of the mixture inside the furnace [10,11]. For the generation of endothermic, exothermic and dissociated ammonia atmospheres, nickel-based catalysts are used. Spent catalyst can be considered a solid waste.

<u>Mass transfer mechanisms during sintering:</u> Evaporation-condensation mechanisms are likely to contribute to the generation of emissions during sintering. Materials that have reported to exhibit a large sintering contribution from evaporation-condensation include NaCl, PbO, TiO_2, Si_3N_4, BN, and ZrO_2, but materials that exhibit weight loss during sintering (beyond adsorbed impurities) are suspected of vapor transport processes. Preferential evaporation of one of the constituents of the alloys or compounds during sintering generates additional air emissions [12].

<u>Operational problems during sintering:</u> Other emissions could originate due to operational problems of the sintering furnace. As sintering temperature increases, there are few compatible materials for the heating elements inside the working zone of the furnace. If the proper atmosphere is not applied, the heating elements will volatilize and fail. Other problems involve instability and reaction of the heating material with carbon and oxides, which becomes a problem in high-temperature furnace operation [12].

To improve the surface finish of the parts after sintering, secondary operations for deburring and cleaning are required to eliminate the sharpness and residues on the surface. Typically organic chlorinated solvents are used for cleaning, although alkaline solutions, methanol, emulsifiers, glycol ethers, and pressurized water are also used. In the case of organic solvents, four halogenated solvents are of common use to clean and condition metal surfaces of P/M parts: methylene chloride (MC), trichloroethylene (TCE), perchloroethylene (PCE), and 1,1,1 trichloroethane (TCA). Emissions from solvent cleaners originate from sources such as: diffusion or evaporation of solvent from the air-solvent vapor interface, evaporation of solvent from cleaned parts as they are withdrawn from the cleaner, equipment leaks, solvent storage, transfer losses, start-up losses, filling-draining losses, and losses due to decomposition. The majority of solvent consumed in cleaning is lost to the air, some is lost to disposal of cleanout waste and distillation residue, and minor amounts may end up in facility wastewater [13].

Liquid wastes associated with other secondary operations (such as grinding and machining) include spent lubricant and oils. The oily waste contains small particles of metal, previously removed from the part. The presence of solids in the oil makes it difficult for reuse and hence it is considered a waste [10]. If a plating operation is utilized, potential liquid wastes of spent solutions include different metallic and non-metallic ionic composition, which could include buffers, acids, accelerators, chelators and inhibitors [14].

7. Toxics Release Inventory for the P/M Industry

The EPA TRI contains information about more than 650 toxic chemicals that are being used, manufactured, treated, transported, or released into the environment. The most recent available data are reported for 1998. Data in TRI reports incorporate submissions and revisions up to March 29, 2000 from the year 1988 to 1998. TRI data reflects chemical releases and other waste management practices, it does not reflect exposure of the public to those chemicals [15].

As EPCRA Section 313 requires, the owners or operators of facilities subject to this annual reporting requisite must report released quantities to the air, water, on-site land, injection wells, as well as discharges to publicly owned treatment works (POTW) and transfers to off-site locations for proper treatment, storage or disposal [15]. The facility emissions could be released either routinely or as a result of an accident. Owner or operator of facilities that manufacture, import or process any of the listed toxic chemicals in amounts equal or greater than 25,000 pounds in a calendar year, are required to report by July 1st of the following year. The owner or operator of a facility that “otherwise uses” any of the listed chemicals in amounts equal or greater than 10,000 pounds in a calendar year is required to submit a toxic chemical release form on each chemical listed, by July 1st of the following year [8,15].

Releases are categorized as follows:

a. *Releases to air:* fugitive or non-point air emissions and stack or point air emissions.

b. *Releases to surface water:* discharges to streams, rivers, lakes, oceans, and other bodies of water.

c. *Disposal to land on-site:* toxic chemical release to land within the boundaries of the reporting facility. This includes disposal in landfills, land treatment, land farming, surface impoundment, and other land disposal methods.

d. *Underground injection:* subsurface emplacement of fluids through wells. TRI chemicals may be injected into Class I, II, III, IV, or V wells, if they do not endanger underground sources of drinking water, public health or the environment.

e. *Total on-site releases:* total quantities of air emissions, surface water discharges, underground injection and on-site land releases.

f. *Total transferred off-site:* total amount of the toxic chemical transferred from the facility to an off-site location or to POTW, for final disposal, not including any recycling or materials recovery.

g. *Total Releases:* total amount of on-site releases and off-site transfers [15].

8. Procedure to Estimate Releases

The majority of P/M companies included in this study are members of the Metal Powder Industries Federation (MPIF). The member categories considered are powder metallurgy parts association and metal powder producers. Some companies are also members of the North American P/M Houses, Custom or Captive [16,17].

Data on environmental information that was self-reported by P/M companies were retrieved from two databases:

- EPA Office of Environmental Information, Toxics Release Inventories on-site and off-site Database (TRI explorer) [15].

- EPA Office of Environmental Information, Environmental Facts Database, (also known as Envirofacts Warehouse) [18].

The main search criterion was based on the Standard Industrial Classification (SIC) for the companies that best describes the activities conducted at the facility or establishment [19].

There are no specific codes for P/M parts manufacture or powder production; these facilities report under the broader classifications. Some companies fall under SIC 3399 for "Primary metal products, not elsewhere classified". Other companies fall under SIC 3499 for "Fabricated metal products, not elsewhere classified", SIC 3714 for "Motor vehicle parts and accessories", or SIC 3999 "Manufacturing industries not elsewhere classified". Table 3 shows the distribution of SIC codes among facilities studied.

Table 3: SIC code distribution among facilities studied

SIC Code	Description	Number of Facilities	Percent of Total
3399	Primary metal products n.e.c.	28	38.9
3499	Fabricated metal products n.e.c.	25	34.7
3714	Automotive parts and accessories	8	11.1
34XX	Various fabricated metal products	11	15.3
	Total	72	100.0

The two databases were searched based on appropriate SIC codes for P/M related facilities. In total data for 72 facilities were tracked. Data were collected on the following considerations:

- Data for releases were collected corresponding to each of the seven on-site and off-site categories, described previously in Section 7.

- Two years, 1993 and 1998, were selected for investigation. Only the facilities that reported in both of these years were considered.
- EPA is responsible for regularly updating the list of hazardous wastes, adding chemicals to the list. In this investigation, data were compared for the majority of the chemicals that were reported in both years, but also additional chemicals were tracked.
- Companies are identified in TRI by a “Facility ID number” that could change, for example when a facility changes ownership or changes the nature of its business [21]. In this study, all the facilities maintained their identification numbers.

There are some limitations to the use of TRI data for environmental performance and evaluation. TRI data only include hazardous materials, and do not track other types of releases that might still affect the environment.

Other tracking problems occur when chemicals or specific uses of chemicals are eliminated from the list, becoming “delisted chemicals”. Facilities are not required to report delisted chemicals, even if they continue to use them, although the quantities of the chemical reported prior to delisting are included in the release inventory. Because the delisted chemical is not included reduced quantities are reported, but this does not necessarily mean that the company reduces its use.

Some of the data on hazardous material use is not reported if companies claim reportable data as “trade secret”. In this case, although they still have to report the information, it is not included in the public data presented in TRI. Companies are allowed to claim reportable data as trade secret in order to protect proprietary manufacturing processes [21].

9. TRI Trends for P/M Industry

The results of the investigation are reported and an overview is presented on the quantity and quality of production-related wastes and emissions, and the corresponding management practices for the P/M industry. In this Section general trends are presented, followed by a discussion on specific releases and trends for specific sectors. A final summary is included as well.

9.1 General Trends

Figure 1 shows the releases from the 72 facilities in 1993 and 1998, with releases categorized by air emissions, surface water discharges, land releases, underground water injection, total on-site releases, total off-site releases and total releases. Air releases for the P/M industry are the most significant in terms of weight. For parts and powder sectors combined, 99.1 % and 98.3% of on-site releases for 1993 and 1998 correspond to air emissions. These air releases represent 84.8% and 76.3% of total releases and transfers for 1993 and 1998 respectively. There is a decrease of air releases for the P/M industry, from 1,205,308 pounds in 1993 to 918,518 pounds in 1998, for a reduction of

23.8%. This reduction in air releases determines a reduction of 24.4% for total on-site releases, during the five-year period for the P/M industry.

During both years, released weights of chemicals in the seven categories studied are higher for parts producers than for powder producers. Further analysis of trends for powder and parts manufacturing sectors is discussed in Section 9.3.

Surface water discharges, land releases and underground water injection have a negligible contribution to on-site releases for both years, when compared to air emissions and transfers off-site. With respect to transfers off-site, this segment represents the 13.2% and 22.9% of total releases for 1993 and 1998 respectively. There is an increase 41.6% in transfers off-site from 195,348 pounds in 1993 to 276,624 pounds in 1998. This reveals that in the P/M industry, the management of solid wastes is associated with transfers to other facilities either for reclamation, recovery of materials, incineration, or for final disposal in appropriate landfills.

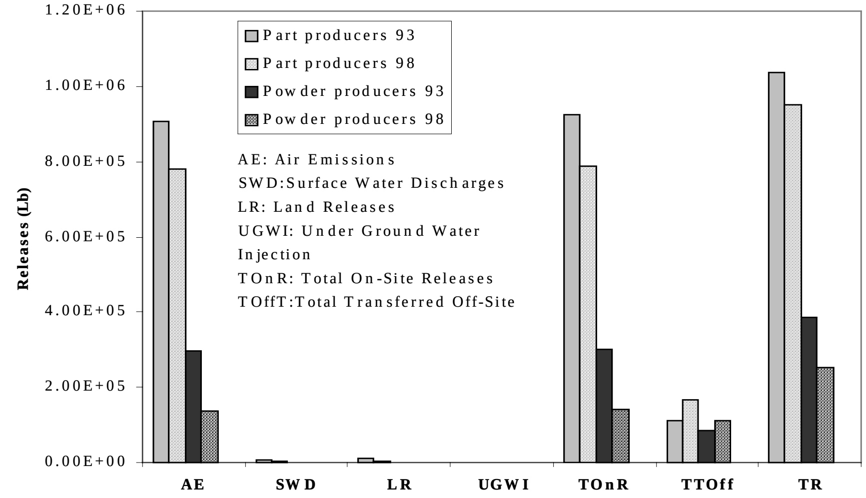


Figure 1: P/M industry releases for 1993 and 1998

Table 4 illustrates the TRI total on-site and total transfers off-site releases, for the P/M industry. For the year 1993, the 72 facilities studied reported a total of 1,420,881 pounds of toxic chemical releases. In 1998, the total releases accounted for 1,203,163 pounds. This corresponds to a reduction of 15.3% in total releases and transfers associated with production, for the five-year period, during which it is fair to consider that the industry experienced growth.

Table 4: Summary of chemical releases and transfers for the P/M industry

Releases and transfers	1993	1998	% Change
On-site releases	1,225,533	926,539	- 24.4
Off-site transfers	195,348	276,624	+ 41.6
Total releases and transfers	1,420,881	1,203,163	- 15.3

For the percentile change of releases and transfers (+) is increase, and (–) is decrease.

9.2 Specific Releases from P/M Facilities

In 1993, Volatile Organic Compounds (VOC's), represented 65.9% of total releases, and 77.7% of air emissions, while in 1998, VOC's contributed 65.1% of total releases, and 84.55% of air emissions. There was a reduction of 19.9% of total VOC's between 1993 and 1998. The relevant compounds contributing to VOC's in air emissions for 1993 and 1998 are listed in Table 5.

Table 5: Volatile Organic Compounds in air releases for the P/M industry

Compound	**% in air emissions, 1993**	**% in air emissions, 1998**
Alcohols (mostly methanol)	35.60	54.26
Aromatics (BTX)[a]	19.48	13.60
Trichloroethane (TCA)	15.39	-
Trichloroethylene (TCE)	11.26	19.61
Tetrachloroethylene (PCE)	0.0	2.83
Methylene chloride (MC)	7.79	6.83
Glycol ethers	4.76	0.0
Ketones	5.72	2.78
Total	100.0	100.0

[a] BTX: aromatic compounds benzene, toluene and xylene.

In 1993, metals represented 32.8% of total releases, 20.8% of air emissions and 99.8% of transfers off-site, while in 1998 metals accounted for 34.5% of total releases, 14.9% of air emissions and 99.7% of transfers off-site. Although the actual pounds per year of metals in air emissions and transfers off-site are the same order of magnitude, when compared to actual pounds of VOC releases, the metal releases to air contribute roughly 20% for both years. Common waste management practice for metal-bearing solid wastes is to transfer them to other facilities for reclamation or final disposal. Table 6 presents a summary of the relevant metals in P/M industry releases.

Table 6 indicates the most significant metals in air emissions: copper, chromium, zinc, nickel, manganese and aluminum and their compounds. For 1993, copper showed the highest percentage (52.43%) of the metallic air emissions (based on the total weight of metals in air emissions). In 1998, zinc had the highest percentage (42.16%) of the metallic air emissions. The trend for transfers off-site, shows copper, chromium, zinc, nickel, and manganese as the most relevant compounds for both years. During 1993 and 1998, copper showed the highest 40.26% and 40.73% respectively percentages of metallic transfers off-site, based on the total quantity of metals in transfers off-site.

Table 6: Metal compounds in metal air releases and metal transfers off-site for the P/M industry

Metal and its metallic compounds	% of metallic air emissions for 1993	% of metallic air emissions for 1998	% of metallic transfers off-site for 1993	% of metallic transfers off-site for 1998
Copper	52.43	27.17	40.26	40.73
Chromium	28.67	5.38	14.37	2.74
Zinc	12.15	42.16	9.00	8.60
Nickel	2.31	6.66	11.13	11.62
Aluminum	2.33	6.39	0.11	0.27
Manganese	1.18	10.01	23.40	32.95
Cobalt	0.69	1.09	0.87	1.42
Lead	0.23	0.76	0.71	1.67
Molybdenum	0.01	0.38	0.15	0
Total	100	100	100	100

Other substances reported in P/M TRI's include ammonia and inorganic compounds, such as hydrochloric acid, sulfuric acid, and sodium nitrite. The quantities of ammonia and inorganics are not significant either as air releases or transfers off-site, when compared to VOC's and metals.

Figures 2 and 3 show respectively the distributions of the majority of chemicals in total air emissions and transfers off-site for 1998. (The distributions for 1993 are quite similar).

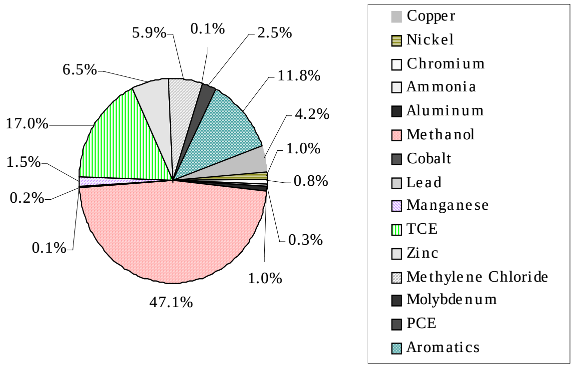


Figure 2: Chemicals in air releases in 1998

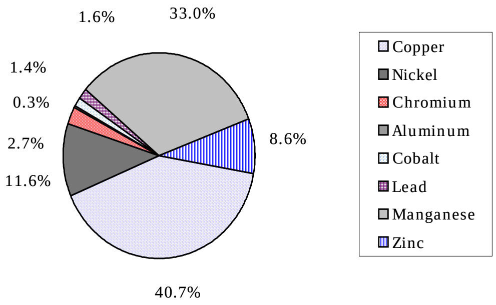


Figure 3: Chemicals in transfers off-site in 1998

The total number of chemical compounds reported in P/M TRI's decreased, from 21 in 1993 to 20 in 1998. Of all the chemicals present in releases and transfers off-site in 1993, four chemicals were not present in releases for 1998 (dichloroethane, hydrochloric acid, sulfuric acid and trichloroethane), while two new chemicals (not present in 1993) were added in 1998 (diethylhexylphthalate and sodium nitrite). The non-aerosol form of hydrochloric acid was removed from the TRI list in 1995, while the non-aerosol form of sulfuric acid was delisted in 1994. Currently, only airborne forms of these two acids are reported. Diethylhexylphthalate, sodium nitrite, dichloroethane and trichloroethane have been in the TRI list since 1986, with no modifications.

The releases for hydrochloric acid, sulfuric acid, dichloroethane, diethylhexylphthalate and sodium nitrite correspond to isolated cases (different facilities). These compounds were not reported for the rest of the facilities studied. This could suggest a special application or process, particular to these facilities, but it could also suggests that the quantities in use for the rest of the facilities maybe below the required amount for reporting to TRI. There is no way to clarify this from the TRI data. Nevertheless, it is fair to say that chemical compounds reported for the facilities under study are well-defined and consistent.

9.3 Specific Sectors: Comparison of Powder and Part Production

Within the group of 72 facilities, 12 (16.67%) correspond to powder producers, and 60 (83.33%) correspond to part producers. Although manufacturing processes are different between both sectors, the behavior for total emissions and releases is similar. In both sectors the majority of on-site releases correspond to air emissions. Table 7 summarizes the data presented in Figure 1.

Table 7: Air emissions, transfers off-site and total releases for powder producers and part producers during 1993 and 1998

Releases (lb)	Powder producers	Percent Change	Part producers	Percent Change
Air releases 1993	298,594		906,714	
Air releases 1998	138,807	-53.51	779,711	-14.0
Transfers off-site 1993	85,283		110,065	
Transfers off-site 1998	110,800	+29.92	165,824	+50.66
Total releases 1993	385,026		1,035,860	
Total releases 1998	250,829	-34.85	952,334	-8.06

For percentage change: (+) is increase and (-) is decrease.

The percentile changes in air emissions and total releases indicate that the powder producer facilities show a greater reductions in both categories during the five year period, when compared to the part producers. In the case of transfers off-site, both groups increased the amount of wastes managed off-site, but the powder producer maintained the lowest percentile increase.

It is difficult to compare the total quantities for releases and emissions, given the disparity in the number of facilities within each sector. Having more facilities manufacturing parts means more raw material usage, and potentially, more waste generation. Therefore, it is more meaningful to look at average emissions and releases for each group. The average of emissions and releases per facility is presented in Figure 4. In all cases, except for air emissions during 1998, powder producers have higher average values of emissions and releases per facility, compared to part producers.

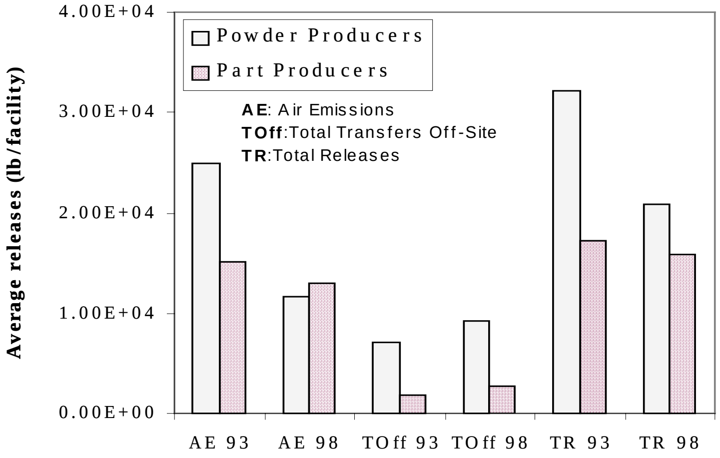


Figure 4: Average emissions and total releases per facility for part and powder manufacturers in 1993 and 1998

9.3-a Trends for Powder Producers

The major contributions to air releases in the powder production sector result from metals and VOC's. Metals account for 69.29% and 50.45% of air releases for 1993 and 1998 respectively, while VOC's account for 30.70% and 49.54% for the same years as shown in Figure 5.

Within the metals, the most significant contributions are those of copper, chromium and zinc. For VOC's the most significant contribution corresponds to methylene chloride (MC), and trichloroethylene (TCE), in both years.

Between 1993 and 1998, a reduction in the quantity of metals released to the air is observed for copper and chromium, while zinc, manganese, aluminum cobalt, lead, and molybdenum air releases increased. Despite these increases, the significant reductions in copper (77.44%) and chromium emissions (90.85%) have led to a global reduction of 66% in metallic air releases. For MC there is a reduction of 28.11%, and for TCE the reduction in air releases is 37.02%.

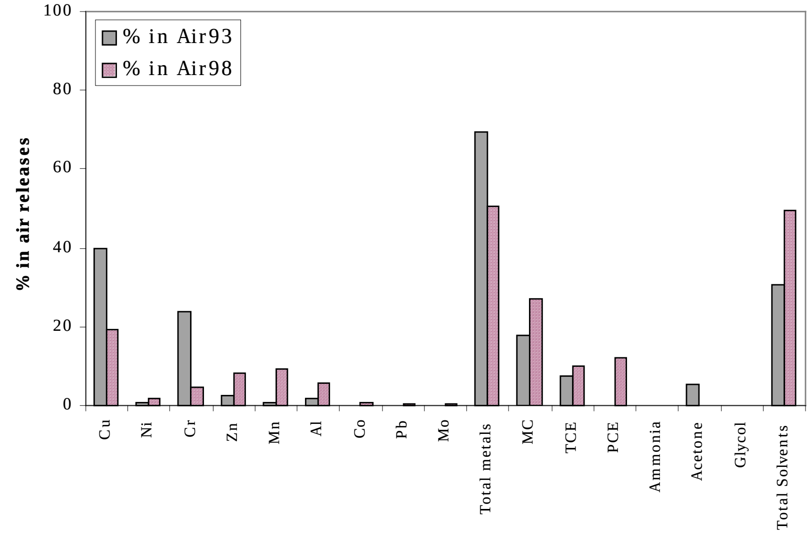


Figure 5: Chemical compounds in air releases for powder producers, during 1993 and 1998

The relevant toxic chemicals in transfers off-site for powder producers are exclusively metals. Metals account for 100% of transfers off-site for both years. Within the metal transferred off-site, the most significant weight contributions are those of manganese and copper. Between 1993 and 1998, the amount of metals transferred off-site increased for manganese, nickel and zinc, while chromium and copper transfers decreased. The reductions in transferred weights of copper (25.3%) and chromium (95.9%) did not offset the increase of 29.68% in metallic transfers off-site for powder producers.

9.3-b Trends for Part Producers

Figure 6 shows the distribution of chemicals in air emissions during 1993 and 1998 for part producers. The relevant contributions of chemicals to air emissions for part producers are significantly different than those of powder producers, where considerably less metal is emitted, compared to VOC's. Metals account for only 4.52% and 8.59% of air releases for 1993 and 1998 respectively, while VOC's account for 95.47% and 91.4% for the same years. Within the metals, the most significant contributor is manganese.

Focusing on VOC's, a total of nine compounds are reported, from which four are halogenated, and five are non-halogenated compounds. The most relevant contributions to weight correspond to alcohols (mainly methanol), aromatics (benzene, toluene and xylene), and TCE. Between 1993 and 1998, there was a reduction in the amount of aromatics, ketones, and MC released to the air, while TCE, and alcohols air releases increased. The total weight of VOC's in air releases decreased 16.65% during the five year period.

Metals account for 100% of transfers off-site, for both years. For 1993 manganese, copper and chromium are the predominant transfers, but for 1998 there is a shift from manganese to nickel. Between 1993 and 1998, an increase in the amount of metals transferred off-site is observed for copper and nickel, while chromium, zinc and manganese transfers decreased. The reductions in chromium (43.2%), manganese (57.35%), and zinc (71.15%) transfers did not offset the increase of 93.82% in total metallic transfers off-site for part producers.

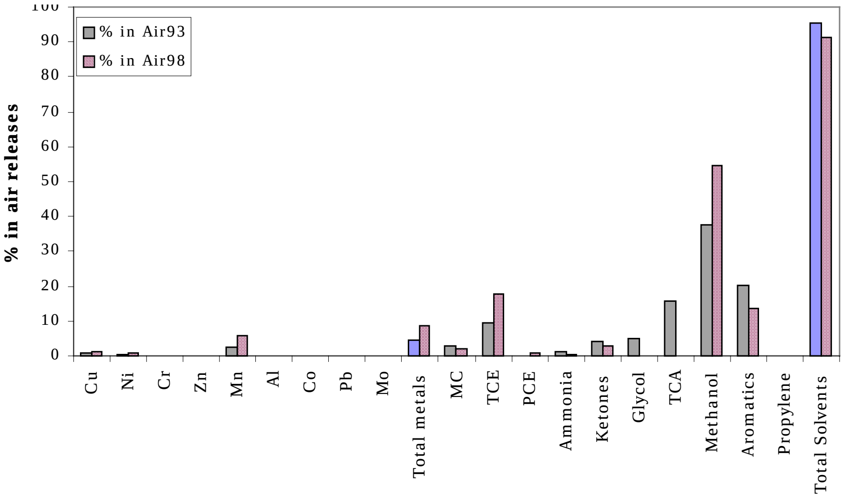


Figure 6: Chemical compounds in air releases for part producers in 1993 and 1998

9.4 Summary of Trends and Discussion of Emission Sources

For powder producers, metals show the greatest contribution to air emissions, and transfers off-site are exclusively metallic in nature. The sources of air emissions in powder production, considering atomization as the main fabrication route, could be attributed to the melting of raw metals, and the handling operations of the finished powder for packing and distribution. Minor contributions of VOC's are associated with vaporization during cleaning operations. This is consistent with the trends that indicate no VOC's present in wastes transferred off-site.

Alternatively, for part producers, VOC's are the predominant air emission. The production of parts involves various operations that require the use of different machines and tools. The cleaning of these machines determines the use of solvents and cleaning agents that in turn have a high contribution to air releases through vaporization.

Despite the weight of halogenated solvents in VOC's, methanol is the main contributor in terms of weight. Although methanol could be used as a cleaning agent, its most important use is in the production of a particular sintering atmosphere, to which a significant contribution of methanol in the weight of VOC air emissions is likely. This could also explain why methanol is not present in VOC emissions for powder producers, since there are no sintering processes in the production of powders. Similarly, ammonia is another compound mainly present in air emissions of part producers, but not for powder producers. Ammonia gas is used to produce a nitrogen-based atmosphere for sintering.

During various operations in part manufacture, there could be a significant contribution of particulate matter and fumes of metals released to the atmosphere. These operations include mixing, pressing and sintering. Powders are in motion inside the mixer, then flowing to the die, and finally pressed and sintered. Air emissions can originate due to dispersion of particles into the air during any of these operations.

When the “green” compact is introduced into the sintering furnace, the delubing step takes place first, where the lubricant (most likely to contain some metal) will be vaporized. Another mechanism that takes place is the elimination of oxide impurities in the green part. These are transformed by the thermal reactions to reduced metals that could be emitted. Preferential vaporization of certain metals from the solid matrix, due to surface mass transfer could also be a source of air emissions during sintering.

Transfers off-site for part producers and powder producers are entirely composed of metals. This behavior is associated with scrapped solid materials that do not meet the specification of the manufacturing processes. Other wastes that could contain metals are cleaning solutions and cutting and grinding oils for secondary operations during part fabrication.

The distribution of metallic species in air releases for both part and powder producers is very consistent in terms of the most significant metals. For powder producers and part producers, the five main emitted metals out of a total of nine are the same: copper, nickel, chromium, manganese and zinc. They are important alloying elements for iron and steel powders, and also copper itself is relevant as a base powder used in many applications. Releases of zinc not only are attributed to the alloys that could possibly contain it, but also to its presence in stearate based lubricants (zinc stearate).

10. Complementary Approaches to Measure Environmental Trends

A more in-depth evaluation of the environmental performance of the P/M industry is one of the goals of this ongoing research. Another major goal of this work is to suggest options for pollution reduction in the P/M industry, in light of the existing TRI emission trends. Two approaches for future work are underway. The first is the adoption of a ranking system based on weight averaged indices for releases of chemicals, according to their toxicity. This system will provide insights on the potential hazard of selected releases in P/M manufacturing processes. The second approach deals with the use of economic data related to production, to normalize emissions and releases over a period of five years. The normalization allows for more realistic comparisons between waste production and industry/sector growth. The following section explains the suggested approaches for future work.

10.1 Toxic Indices Approach

The American Conference of Governmental Industrial Hygienists has created a standard for concentration of air-borne chemicals, which is a Time Weight Averaged Threshold Limit Value (TLV-TWA). The TLV is a concentration in air that must not be exceeded during any 8-hour work shift of a 40-hour work-week. For the chemicals under consideration for the P/M industry, the TLV range is extremely broad: 0.05 to 1,910 mg/m^3. Figures 7 and 8 show the difference in TLV's for metals and other compounds. Within TRI releases, chemicals that are higher ranked due to mass discharges for a given process may not be as toxic or persistent in the environment, when compared to other lower ranked chemicals. These lower ranked chemicals may be substantially more toxic and persistent.

There are many weighting systems for analysis and indexing of toxic chemicals, and the equivalent toxicity index method that will be used for the P/M industry analysis, was developed at Carnegie Mellon University [22]. The Carnegie Mellon University equivalent toxicity method (CMU-ET) suggests weighting TRI discharges by using the American Conference of Governmental Industrial Hygienists Time Weight Averaged Threshold Limit Value (TLV-TWA). This method can be used as a measure for environmental performance by computing equivalent toxicity indices for selected releases.

Since the method deals with discharges, it does not consider fate and transport of the chemicals, and it is not intended to measure direct human exposure and health effects, because information on dose-response relationship is not included. It is also important to note that synergistic or antagonistic effects of chemical mixtures are ignored for the P/M industrial system, because there is insufficient data on interactions between chemicals. The CMU-ET method is convenient, given it is not data intensive, and the inputs are TRI weights of releases and Threshold Limit Values.

10.2 Production Baseline for Normalization of Releases

In 1994, EPA launched the Common Sense Initiative (CSI), to explore industry-specific strategies for environmental protection. The program is designed to promote "cleaner, cheaper and smarter" environmental performance, through the reduction of pollutants released to different media, and the selection of best technological options for overall pollution reduction within industrial sectors.

In 1995, EPA established a CSI subcommittee for the metal finishing industry, that included representatives of EPA, metal finishing industry and its suppliers, state governments, POTW, environmental organizations and organized labor. The goal was to test innovative ideas and policy actions for pollution reduction in the metal finishing industry. The program established a set of voluntary National performance goals. The goals include facility-based numerical performance targets that track the CSI themes of improved resource utilization, reduced hazardous emissions and exposures (for organic TRI and metal emissions, hazardous sludge disposal, sludge generation, and worker and community exposure), and improved economic performance and reduction of "unnecessary" compliance cost. The program calculates environmental performance by comparing current environmental data to data from a baseline year, for a given company. The normalized calculations are applicable to water discharges, solid sludge production and its transfer off-site, energy use, organic emissions, and metal discharges. An overall score is calculated by weighting various criteria for reduction and conservation: 50% reduction in land disposal of hazardous sludges, 50% reduction in metal emissions to air, 98% metals utilization, and 90% reduction in organic emissions, 50% water usage reduction, and 25% energy usage reduction [24].

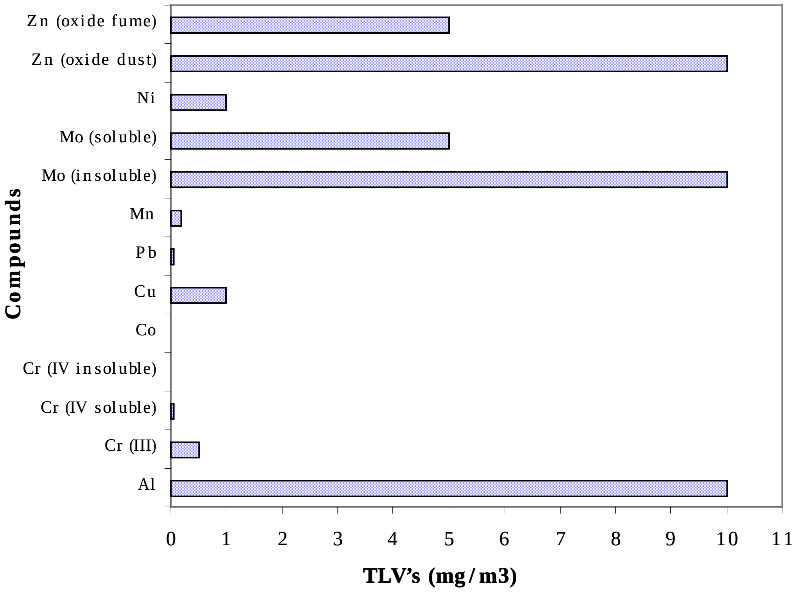


Figure 7: Threshold Limit Values (TLV-TWA) for metals in P/M industry [23]

This same approach could be applicable to the P/M industry, given the availability of TRI data for performance calculation on emissions and solid waste releases. To compute the scores, units of production in dollars or by shipments for the companies in the P/M sector, during selected years, and inflation rates are required.

As discussed in Section 4, general U.S. Census data for the P/M industry does not provide the level of detail needed to evaluate companies using the baseline method. Industry collaboration will be of key importance in gathering data for the application of this methodology.

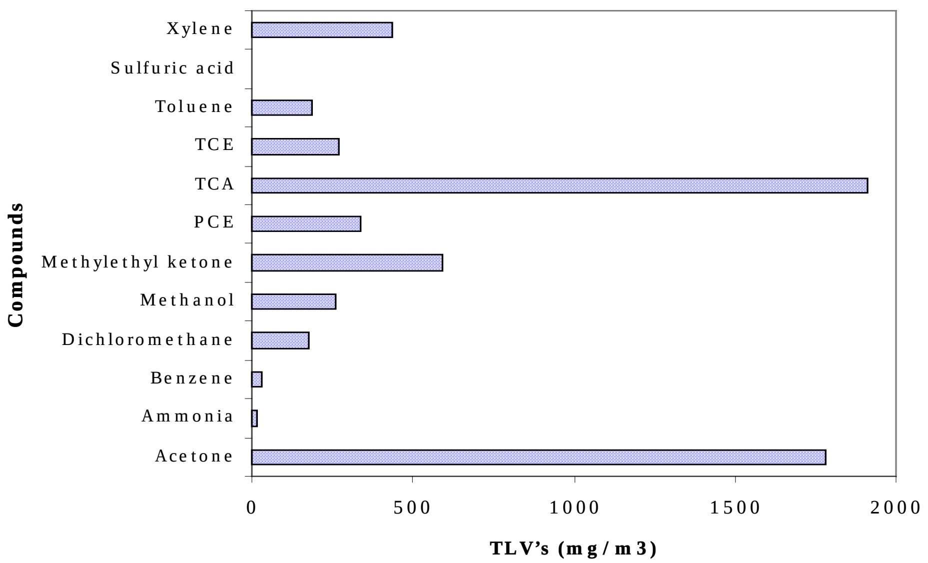


Figure 8: Threshold Limit Values (TLV-TWA) for inorganic and organic compounds in P/M industry [23]

11. Future work

Development of cost assessment tools for pollution prevention options combined with TRI based studies will allow identification of viable opportunities for pollution reduction and more sustainable manufacturing processes for the P/M industry. While literally hundreds of strategies could be investigated, the most likely scenarios considered for pollution cost and tradeoff assessment will be those involving air and wastes derived from TRI analyses. The identification of technical options to reduce wastes and emissions in the P/M manufacturing cycle, alternative management practices, and changing incentives will be the expected outcomes of this work.

12. References

[1] Verschoor, A.H and L. Reijnders. *Toxics reduction in ten large companies, why and how*. Journal of Cleaner Production, vol 8, pp 69-78, 2000.

[2] European Powder Metal Association (EPMA), http://www.epma.com

[3] Metal Powder Industries Federation (MPIF), http://www.mpif.org

[4] Apelian, D. et al. *Competitive and economic performance in the Powder Metallurgy Parts Industry*. In American Industrial Resurgence: Sources and Prospects. Washington D.C.: National Academy of Sciences, 1998.

[5] U.S. Census Bureau. *1997 Economic Census. Powder Metallurgy Parts Manufacturing*. U.S. Department of Commerce, October 1999.

[6] *Code of Federal Regulations, Protection of the Environment*. Washington D.C.: Federal Register National Archives and Records Administration. U.S. Printing Office, 1990.

[7] *Profile of the Fabricated Metal Products Industry. EPA Office of Compliance Sector Notebook Project.* Washington D.C.: U.S. Environmental Protection Agency, 1995.

[8] *Environmental Law Handbook*, 12th edition. Rockville, MD: Government Institutes Inc., 1993.

[9] Carson, B.L., H. Ellis and J. McCann. *Toxicology and biological monitoring of metals in humans*. Michigan: Lewis Publishers Inc., 1987.

[10] German, R.M. *Powder Metallurgy Science.* 2nd Edition. New Jersey: Metal Powder Industries Federation, 1994.

[11] *ASM Handbook: Powder metal technology and applications,* vol. 7. ASM International.

[12] German, R.M. *Sintering Technology and practice.* New York: John Wiley and Sons Inc., 1996

[13] *Halogenated solvent cleaners*. New Jersey: Noyes Data Corporation, 1990.

[14] *Metals Handbook, desk edition.* 2nd Edition. Ohio: ASM International, 1998.

[15] Toxics Release Inventory Database Environmnetal Protection Agency, http://www.epa.gov/triexplorer/

[16] *Who's Who in P/M. 2000 Membership Directory.* New Jersey: APMI International, 2000.

[17] Powder-Tech Associates Inc., http://www.powder-tech.com

[18] Envirofacts database, Environmental Protection Agency, http://www.epa.gov/enviro/html/multisystem_query_java.html

[19] *Statistics for industry groups and industries, 1996 annual survey of manufacturers.* U.S. Census Bureau, 1998.

[20] Bridge between NAISC and SIC manufacturing, 1997 U.S. economic census, http://www.census.gov/epcd/ec97brdg/E97B1332.htm

[21] The Massachusetts Toxics Use Reduction Institute, http://www.turi.org

[22] Horvath, A., C. Hendrickson, L. Have, F. McMichael and T-S. Wu. *Toxic emissions indices for green design and inventory.* Environmental Science and Technology, vol. 2, 92, p 86A-90A, 1995.

[23] *Toxicology desk reference 1997-1998* (1997). 4th edition. Ryan, R. and C. Terry Editors. USA: Taylor and Francis publishers, 1997.

[24] National Strategic Goals Program for the Metal finishing industry, http://www.strategicgoals.org