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A SYSTEMIC COST MODEL FOR HIGH MIX LOW VOLUME METAL PROCESSING SMALL AND MEDIUM MANUFACTURERS

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Abstract
Small and medium enterprises with a high mix and low volume of products face unique challenges that require a detailed understanding and accurate allocation of enterprise, shop floor and operation costs in order to make pricing, management, and strategic decisions. Traditional cost modeling methods have limitations in managing cost distortion, leading to vast disparities between perceived and actual costs of products. Although research has demonstrated improvements in effective cost management through implementation of activity-based costing, current models are not easily accessible to SMEs management, especially high mix low volume manufacturers. In order to provide a practical and easily accessible cost modeling method for understanding and improving SME manufacturing systems, this study separates the manufacturing system into enterprise, shopfloor, and operation levels and demonstrates the developed cost models at each level with an actual manufacturing case. The results show that by allocating overhead costs from the enterprise, shop floor and operation levels of manufacturing systems to the cost of an individual product, management will be effectively assessing the value of each product, making better-informed decisions, and ultimately improving the competitiveness of their enterprise.

Keywords
Cost modeling, High mix low volume, Small and Medium Enterprises, Life cycle costing, manufacturing systems.

Introduction
Cost information is a critical factor for effective management in manufacturing enterprises. As overhead costs continue to rise, traditional cost accounting methods are becoming less capable of producing data accurate enough for management to utilize (Kaplan and Anderson, 2003). Although methods such as activity-based costing and process-based costing have been successfully implemented in larger companies with the resources and stability to afford the change, small and medium manufacturing enterprises are still largely rooted in traditional costing methods (Roztocki, 2005).

U.S. Department of Commerce defines an SME in the manufacturing and service industry is an enterprise with fewer than 500 employees (USDOC, 2012). An HMLV enterprise is one that produces a variety of products differing in application, lot size, and production process (JABIL, 2014). Product mix is a large part of a company's success, as consumers tend to purchase portfolios of products rather than individual products (Andrews et al., 2014). Although high product mix can often give an enterprise a competitive advantage, this advantage is attained only with marketing and manufacturing efficiency (Berry and Cooper, 1999).

High-mix, low-volume (HMLV) small-to-medium enterprises (SMEs) have traditionally been more diverse and flexible than their larger, high-volume counterparts (Kaplan and Anderson, 2003). HMLV SMEs face unique challenges, such as misinterpretation of their manufacturing process costs and inconsistent product pricing (Girod et al., 2014). A cost model well-suited to the changing environment of HMLV SMEs will allow management to meet its unique challenges more efficiently. However, current costing methods commonly utilized in HMLV SMEs fail to fully meet these challenges while newer, unfamiliar cost models are less likely to be implemented in SMEs due to their expenses and perceived complexity (Roztocki, 2005).

In order to increase the accessibility of cost models suitable for HMLV SMEs, the proposed cost model emphasizes simplicity and economy. The model separates costs into three levels: enterprise level, shop floor level, and operation level. Enterprise costs include expenditures such as administration, marketing, and freight, which are necessary for the functioning of the factory but not directly allocable to an individual product. Shop floor costs include costs of lighting, safety devices, and ancillary materials; these costs are also not directly allocable to an individual product. Operation costs include expenses from each process involved in the production of an individual product, and is allocated to each individual product. The model is designed for user-familiar interface to reduce expenses and perceived complexity. This approach is expected to assist HMLV SMEs in understanding their manufacturing cost nature, thereby improving decision making on product pricing, manufacturing system improvement, and policy making.

Literature Review

Costing can benefit HMLV SMEs by providing a more accurate representation of the costs involved with each product the enterprise produces. An examination of prior research involving various types of costing and their application in SMEs shows how different elements of each method affect product costing.

Activity-based costing (ABC) emerged as a more efficient alternative to traditional costing methods (Staubus, 1971). In activity-based costing, each activity is treated as a cost involved in the production of a product or service. Factory and corporate support costs are all allocated, from the top down, to individual product models (Robert Steven Kaplan & Bruns, 1987). Costs are allocated through resource drivers and activity drivers. Resource drivers include units such as time, equipment depreciation, or labor; these are used to determine the "cost" of an activity. The resource costs, once assigned to an activity, are then allocated to cost objects through the use of an activity driver. Activity drivers measure the frequency of the activity (Goebel et al., 1998). ABC recognizes that direct labor hours or dollar sales do not always correctly account for allocation of overhead and other market-based activities, making it a powerful tool for assessing the value of a single product. However, ABC is often difficult to effectively implement in HMLV SMEs due to lack of data, limited technical and financial resources, and inadequate computerization (Roztocki, 2005). ABC may also produce data that is too complex for analysis by less experienced management.

Process-based costing (Banerjee, 2006; Lee et al., 2003; Shim & Siegel, 2000) is a method used most often in enterprises that produce just a few identical products in large batches. In contrast to ABC, costs in process-based costing are allocated to a few processing departments. Processing departments are organizational units that perform a specific job on the product, such as punching or braking. As in ABC, overhead costs are allocated to these units rather than calculated separately (Phillips et al., 2011). Process-based costing can be more effective than ABC at accurately representing cost information because of its simplicity; however, Sievanen and Tornberg noted in their 2002 case study that processes must be clearly defined. It is a less viable option in HMLV SMEs due to the large number of different models and products produced.

Similar to process-based costing, job order costing allocates overhead and enterprise costs to a single unit. In job order costing, costs are allocated to a batch of products rather than to a particular process (Horngren, 1967). As each batch of products will have different production needs, job order costing is better-suited to a manufacturing enterprise with a wider variety of products. Overhead is allocated to batches, often simply by using direct labor hours (Hoque, 2005). For an SME with a HMLV of products, job order costing has the potential to be an effective cost model. However, direct labor hours correlate to overhead costs less reliably in an enterprise where machines replace most direct labor, as they do in a metals manufacturing enterprise.

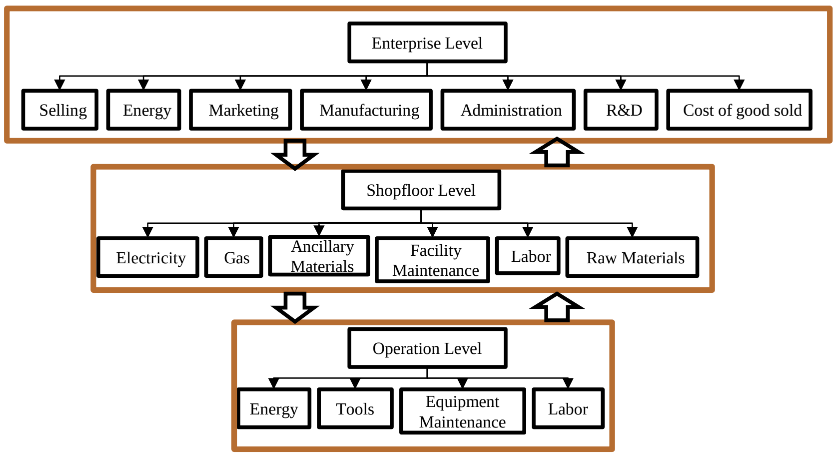
Life cycle costing (LCC) takes into account the entire life of a product when calculating or projecting costs. LCC is the total cost of ownership of machinery and equipment, including its cost of acquisition, operation, maintenance, conversion, and decommissioning (Engineers, 1993). Life cycle costs are summations of all the costs related with the material use, length of equipment life and also annual time increments during the equipment life with considering the time money value (Barringer & Weber, 1996). The objective of LCC analysis is to choose the most cost effective approach from a series of alternatives to achieve the lowest long-term cost of ownership. Usually the cost of operation, maintenance, and disposal costs exceed all other first costs many times over. The best balance among cost elements is achieved when the total LCC is minimized (Landers, 1995). As with most engineering tools, LCC provides best results when conducting a project that is with a time value. On shop floor, LCC can be utilized to assess the costs of equipment and facility with time value.

Common versions of the cost models above are deficient in providing for the specific needs of a HMLV metals manufacturing SME. Methods commonly used in HMLV SMEs today fail to fully account for all the costs involved in the wide, complex range of overhead and products of an HMLV metals manufacturer. Many elements of existing cost modeling methods are integrated in the proposed cost model. It integrates the merits of the top-bottom approach to overhead allocation that is implemented in most forms of ABC while also providing costing information on each process involved in the production of a specific model, as process-based modeling does. By combining suitable elements of a variety of cost models, the proposed model is adapted to suit the specific needs of an HMLV metals manufacturing SME that is looking to transition to greater sustainability (Girod et al., 2014).

Methodology

The proposed cost model seeks to overcome some prominent challenges of implementing an effective cost model in HMLV SMEs through use of a user-friendly interface. To provide a more intuitive and accurate organization of data, the cost model first separates costs into three distinct levels (Exhibit 1): enterprise level, shop floor level, and operation level (Zhang et al., 2013).

Exhibit1. The Systemic Cost Model for HMLV Metal Processing Manufacturers.



This three-level structure between different types of costs simplifies the model and will allow decision-makers to assess the impact of each process, the impact of overhead categories, and the impact of labor expenses on the overall cost of producing a product. Managers will be able to track the flow of expenses normally allocated to a general "overhead" section, such as natural gas or electricity, to individual products. The cost of each process involved in a product's production is shown explicitly for each product, allowing a manager to assess the efficiency of each process both overall and for an individual product. Other costs, such as labor expenses, are also shown explicitly for each product and process.

Enterprise level

Many costs in enterprise level related to the sale, marketing, and administration that can have a large impact on the cost of a product; understanding the impact of these costs separately from the cost of the product will allow managers at the enterprise level to compensate for these costs more accurately.

The expenses involved in the enterprise level includes both manufacturing costs and costs that are not directly related to the production of any products. These costs can be separated into a few major components, such as selling, cost of goods, administrative expenses, marketing expenses, and research and development. Common items that may be included in enterprise level expenses include freight expenses, workers' compensation, and labor for activities such as administration and marketing. For each cost level, different groups of people manage decision-making. At the enterprise level, the chief decision-makers are managers. Managers at the enterprise level make large-scale decisions in a metals manufacturing SME, such as managing inventory and reacting to consumer demand.

Shop Floor level

At the shop floor level, this cost model aims to optimize purchase and storage efficiency for items such as ancillary materials, gases, lighting, and general building maintenance. The costs included in this portion of the cost model are limited to those involving processes or materials in use at the shop floor itself. Items at the shop floor level include the cost of light for each light fixture, mat cleaning and sweeping, and the cost of gas delivery, purchase, and cylinder rental.

At the shop floor level, production engineers make most shop floor decisions. Production engineers control the flow of products through the manufacturing process and make decisions about logistics, supply chain, scheduling, and organizing. The division of costs in this section of the cost model will allow production engineers to understand the impact of machine operation time and lighting systems on production costs.

Operation level

The operation level of the cost model considers costs involved in the various processes in the manufacturing procedure. An effective cost model at this level is necessary for decision-makers to understand the cost of each process as a whole and for an individual product. The operation level of the proposed cost model includes only the costs associated with processes involved in the production of a product, such as punching or braking. The cost model separates the cost of a process into its various components, such as labor, electricity, or any gases used. Decision makers at this level can utilize this data for optimization of energy efficiency, machine efficiency, and potentially for making decisions about product scheduling.

The three level structure in the cost model is intended to emphasize the distinct costs involved in each level while making it possible to observe correlations between various aspects of a process or model. As most overhead costs, as well as direct labor and material expenses, are allocated to a single model, each individual model's profitability is easier to accurately assess. These overhead costs may also be attributable to a process, which can help management identify consistently inefficient processes. As an example, energy expenses are distributed through both the shop floor and the operation level. Energy used for lighting is accounted for under the shop floor level, whereas energy used in production processes is accounted for under the operation level. Managers in an HMLV SME can utilize this model to identify energy-intensive processes; energy-intensive models; and the distribution of energy consumption at the enterprise, shop floor, and operation levels. This system allows management to see how the overall cost of energy is distributed throughout the enterprise, how it is distributed throughout each process, and how it is distributed through each product.

Case Study

This section describes the implementation of the proposed cost model in a medium sized, Oregon-based laboratory equipment manufacturer. This enterprise produces a high mix of products in order to supply a variety of customers at a greater convenience; as a result, the enterprise faces a complex mix of expenses. This enterprise also does not have a consistent model to track and assess these expenses and relies heavily on individual employees' experience and expertise. Currently, the enterprise faces issues with production line efficiency, standardization across products, varying lead time, and inconsistent cost modeling methods. In this study, data is collected for a particular model, which will be referred to as "Model A."

As described above, the systemic cost model includes three levels. The enterprise level cost structure includes selling costs, costs of goods sold, marketing expenses, administrative expenses, R&D expenses, manufacturing costs, and other overhead costs. The shop floor level cost structure includes raw material costs, energy costs, safety ensurance costs, building maintenance costs, overhead and process labor costs, and equipment, tool, and material costs. The operation level cost structure mainly includes energy costs, labor costs, and machine and tool costs. This systemic cost model starts from operation level structure and aggregates the cost information to shop floor and enterprise levels. At each level, the corresponding cost model structure is able to assist decision makers to plan the process, production flow and management.

Operation Level

The primary operations involved in the manufacturing process are punching, bending, welding, painting, assembly, quality assurance, and packaging.

Punch The punch process cuts shaped parts of the product from cold roll or stainless steel sheets. Two series of parts are processed during the punching procedure: standard production and Kanban parts. Standard production parts are processed from raw materials at the enterprise upon receiving an order. Kanban parts are pre-processed and sent directly to punching upon receiving an order. Each part requires specific programs to be punched correctly.

Bending Process The bending process bends processed metal sheets to a certain angle. The bended metal sheets will be conveyed to welding or directly to assembly. There are three bending presses and three operators in the workcell.

Weld Process The welding process joins metal sheets together into a particular part of Model A. The welding work cell consists seven work stations, seven operators, and one supervisor. The welding process includes four sub-processes, weld, PEM, Spot weld, and grind. One operator is also responsible for distributing parts to each sub-process.

Paint Process The painting process has a paint line of 360 feet long and travels at a speed of 4 feet per minute. The operators hang all the parts that need to be painted on the line and get the parts off the line after they go through a full cycle which is usually about 90 minutes. During this process, the part will be painted and then stay in the oven to be dried for 25 minutes. The product models have multiple paint colors, but only two typical colors, white and grey. The paint changeover time is about 25 minutes. There are three operators at this process.

Assembly There are four subprocesses at assembly, pre-assembly, acid wash, door assembly, and assembly. The first three subprocesses can happen simultaneously. In the end, all the parts will be gathered to an assembly line. There are four assembly lines.

Quality Assurance Quality assurance (QA) inspects the product quality and makes sure there is no leak in the chamber and all the functins work well. CO2 or water might be filled to the chamber depending on the product model. There is only one operator at QA.

Packaging Packaging process is the last process of the whole production process. It packs the tested product to a box, insures the product won't be damaged during shipping, and adds related product document (e.g., manual) into the package. There are four operators in this process.

There are three major cost categories at operation level, energy, labor, material machine and tool. These costs, however, are largely dependent on operation parameters (e.g., process time). Therefore, process time calculation is also provided for each process.

Exhibit 2. Variables for Cost Model Operation Level Structure.

Process	**Variables**	**Explanation**
Punch	T_{Punch}	Total process time at punch process
	$T_{Program}$	Program time for punch process
	$T_{Punch\text{-}setup}$	Punch setup changover time
	$N_{Punch\text{-}setup}$	Number of setups
	E_{Punch}	Energy consumption of punch process
	$I_{Cutting}$	Current of punch machine when cutting
	V_{Punch}	Voltage of the punch machine
	I_{Punch_idle}	Current of punch machine when idle
	C_{Punch_labor}	Labor cost for punch process
	W	Average wage
	R_{Fringe}	Fringe rate
	m	Number of programs used for product model A
	D_{Punch}	Functionality depreiciation of the punch machine
	$T_{Punchmachine}$	Total punch machine service hours during use life
	$I_{Punch\_initial}$	Punch machine initial cost
	$S_{Punch\_salvage}$	Punch machine salvage value
	$C_{Maintenance\_punch\_yearly}$	Total maintenance cost for punch tools per year
	$C_{Maintenance\_punch}$	Total maintenance cost for punch tools allocated to one uniti of model A
	$N_{monthly}$	Monthly throughput of all products from the system
Bend	T_{Bend}	Total process time at bending process
	$T_{Bend\text{-}setup}$	Bending setup changover time
	$n_{Bend\text{-}setup}$	Number of bending setups
	E_{Bend}	Energy consumption of bending process
	I_{Bend}	Average current of bending press
	V_{Bend}	Voltage of the bend press
	C_{Bend_labor}	Labor cost
	$D_{Bendpress}$	Functionality depreiciation of the bend press
	$T_{Bendpress}$	Total bend press service hours during use life
	$I_{Bendpress\_initial}$	Bend press initial cost
	$S_{Bendpress\_salvage}$	Bend press salvage value
	$C_{machine\&tool\_bend}$	Total cost of bend machine and tools used in processing 1 unit of model A
Weld	T_{Weld}	Total process time at welding process

	$T_{Weld\_subprocess}$	Welding subprocess time
	E_{Weld}	Energy consumption of bending process
	I_{Weld}	Average current of bending press
	V_{Weld}	Voltage of the bend press
	C_{Weld_labor}	Labor cost
	C_{Tool_weld}	Yearly cost of welding tools
	$C_{Material\_weld}$	Material cost in welding
	$r_{Argon\_cost\_rate}$	Argon purchase cost rate
	u_{Argon_yearly}	Yearly argon use
Paint	T_{Paint}	Total process time at painting process
	n_{paint_large}	Number of large sized parts in model A for painting process
	n_{paint_medium}	Number of medium sized parts in model A for painting process
	n_{paint_small}	Number of small sized parts in model A for painting process
	L_{paint_large}	Length of large sized parts in model A for painting process
	L_{paint_medium}	Length of medium sized parts in model A for painting process
	L_{paint_small}	Length of small sized parts in model A for painting process
	$v_{paintline}$	Paint line move speed
	$T_{paintline\_cycle}$	Paint line cycle time
	$T_{paint\_changeover}$	Paint changeover time
	$n_{paint\_changeover}$	Number of paint changeovers for model A
	E_{Paint}	Energy consumption of painting process
	I_{Paint}	Average current of paintline
	I_{oven}	Average current of oven
	$V_{Paintline}$	Voltage of the painting process
	C_{Paint_labor}	Labor cost at painting process
	C_{Paint_tool}	Cost of paint line tools for one unit of model A
	$C_{Material\_paint}$	Paint cost for model A
	$C_{Tool\_paint\_yearly}$	Yearly cost of paint line tools
Assembly	$T_{Assembly}$	Total assembly time for one unit of model A
	$T_{Assembly\_acidwash}$	Acid wash time for model A
	$T_{Assembly\_preassembly}$	Pre-assembly time for model A
	$T_{Assembly\_doorassembly}$	Door assembly time for model A
	$T_{Assembly\_assembly}$	Assembly line time for model A
	$C_{Assembly\_labor}$	Assembly process labor cost for one unit of model A
Quality Assurance	T_{QA}	Total QA time for one unit of model A
	T_{QA_setup}	Setup time for QA test
	T_{QA_test}	Test running time at QA process
	C_{QA_labor}	Assembly process labor cost for one unit of model A
	E_{QA}	Energy consumption of painting process
	P_{QA}	Running power of model A
	$C_{Material\_QA}$	Paint cost for model A
	u_{QA}	Paint use for one uint of model A
	$r_{CO2\_costrate}$	Paint cost rate
Packaging	$T_{Package}$	Total QA time for one unit of model A
	$C_{Package\_labor}$	Assembly process labor cost for one unit of model A
	$C_{Material\_package}$	Total packaging material cost for one unit of model A
	$C_{Material\_package\_paperboard}$	Paint cost for model A
	$C_{Material\_package\_plastics}$	Paint use for one uint of model A
	$C_{Material\_package\_plasticbag}$	Paint cost rate

These variables (Exhibit 2) and equations (Exhibit 3) are case specific. Additionally, reasonable assumptions are made based on the nature of the process and discussion with shopfloor engineers. Process times are collected from time studies, and energy consumption data is collected with energy monitors implemented on production machines and paintline meters. Punch and Bending press machines use unit of production depreciation method. The paintline uses straightline depreciation method. Some materials, tools are purchased on a yearly basis and they are not regular consumables, however, they cannot be neglected as the dollar amount can be as large as 38.63% of a process cost. Therefore, yearly production volume is used to allocate these costs to a single unit of a product. Table 3 shows the percentage of each cost category at each production process.

Exhibit 3. Equations for calculating Energy, Labor and Material Tool cost at Operation Level.

Process	**Cost element**	**Equations**
Punch	Operation parameters	$T_{Program} = \sum T_{Program\_k}$ $T_{Punch} = T_{Program} + T_{Punch\text{-}setup} * n_{Punch\text{-}setup}$
	Energy	$E_{Punch} = T_{Program} * I_{Punch\_cutting} * V_{Punch} + T_{Punch\_setup} * n_{Punch\text{-}setup} * I_{Punch\_idle} * V_{Punch}$
	Labor	$C_{Punch\_labor} = T_{Punch} * W * (1+R_{Fringe})$
	Machine and Tool	$D_{Punch} = T_{Punch}/T_{Punchmachine} * (I_{Punch\_initial} - S_{Punch\_salvage})$ $C_{Maintenance\_punch} = C_{Maintenance\_punch\_yearly}/ (12*N_{Monthly})$
Bend	Operation parameters	$T_{Bend} = T_{Bend\text{-}setup} * n_{Bend\text{-}setup}$
	Energy	$E_{Bend} = T_{Bend\text{-}setup} * n_{Bend\text{-}setup} * I_{Bend} * V_{Bend}$
	Labor	$C_{Bend\_labor} = T_{Bend} * W * (1+R_{fringe})$
	Machine and Tool	$D_{punch} = T_{punch}/T_{punchmachine} * (I_{punch\_initial} - S_{punch\_salvage})$
Weld	Operation parameters	$T_{Weld} = \sum T_{Weld\_subprocess}$
	Energy	$E_{Weld} = I_{Weld} * V_{Weld} * T_{Weld}$
	Labor	$C_{Weld\_labor} = T_{Weld} * W * (1+R_{fringe})$
	Machine and Tool	$C_{Material\_weld} = r_{Argon\_cost\_rate} * u_{Argon\_yearly}/ (12*N_{monthly})$ $C_{Tool\_weld} = C_{Tool\_weld\_yearly} * / (12*N_{monthly})$
Paint	Operation parameters	$T_{Paint} = (n_{paint\_large} * L_{paint\_large} + n_{paint\_medium} * L_{paint\_medium} + n_{paint\_small} * L_{paint\_small})/ v_{paintline} + T_{paintline\_cycle} + T_{paint\_changeover} * n_{paint\_changeover}$
	Energy	$E_{Paint} = I_{Paint} * V_{Paintline} + I_{oven} * V_{Paintline}$
	Labor	$C_{Paint\_labor} = T_{Paint} * W * (1+R_{fringe})$
	Machine and Tool	$C_{Material\_paint} = u_{paint} * r_{paint\_costrate}$ $C_{Paint\_tool} = C_{Tool\_paint\_yearly} / (12*N_{monthly})$ $D_{paintline} = (I_{paintline\_initial} - S_{paintline\_salvage}) / (T_{paintline} * 12*N_{monthly})$
Assembly	Operation parameters	$T_{Assembly} = T_{Assembly\_acidwash} + T_{Assembly\_preassembly} + T_{Assembly\_doorassembly} + T_{Assembly\_assembly}$
	Energy	Lighting energy consumption is accounted as shopfloor energy use. Therefore, in this process, energy consumption is assumed to be 0.
	Labor	$C_{Assembly\_labor} = T_{Assembly} * W * (1+R_{fringe})$
	Machine and Tool	At assembly, the raw materials used are mostly pins and screws which are already included in the Bill of Material (BOM). The tools can also last a long time which in this study are not counted as regular consumables.
Quality Assurance	Operation parameters	$T_{QA} = T_{QA\_setup} + T_{QA\_test}$
	Energy	$E_{QA} = T_{QA\_test} * P_{QA}$
	Labor	$C_{QA\_labor} = T_{QA} * W * (1+R_{fringe})$
	Machine and Tool	$C_{Material\_QA} = u_{QA} * r_{CO2\_costrate}$
Packaging	Operation parameters	$T_{Package} = 50min$
	Energy	Same as assembly process, the energy consumptions in packaging are used in the lighting and the drills.
	Labor	$C_{Package\_labor} = T_{Package} * W * (1+R_{fringe})$
	Machine and Tool	$C_{Material\_package} = C_{Material\_package\_paperboard} + C_{Material\_package\_plastics} + C_{Material\_package\_plasticbag}$

The result (Exhibit 4) shows that labor cost takes the largest part of process cost, while energy takes the least portion. This indicates at the bottom level of this manufacturing system, labor cost is much larger than equipment and tools cost. Besides, process time is related to energy and labor cost, and also related to punch and bending press when unit of production depreciation is used as the depreication method. Hence, reducing process time can be a potential improvement on reducing manufacturing cost.

Exhibit 4. Cost Composition of Operation Level Manufacturing Processes.

Punch	Cost Category	Percentage	Assembly	Cost Category	Percentage
	Energy	2.37%		Energy	0
	Labor	59.00%		Labor	100%
	Material Tool Mcachine	38.63%		Material Tool Mcachine	0
Bend	**Cost Category**	**Percentage**	**QA**	**Cost Category**	**Percentage**
	Energy	0.05%		Energy	0.13%
	Labor	86.99%		Labor	87.32%
	Material Tool Mcachine	12.96%		Material Tool Mcachine	12.55%
Weld	**Cost Category**	**Percentage**	**Packaging**	**Cost Category**	**Percentage**
	Energy	0.21%		Energy	0
	Labor	74.96%		Labor	97.27%
	Material Tool Mcachine	24.83%		Material Tool Mcachine	2.73%
Paint	**Cost Category**	**Percentage**			
	Energy	0.60%			
	Labor	68.39%			
	Material Tool Mcachine	31.01%			

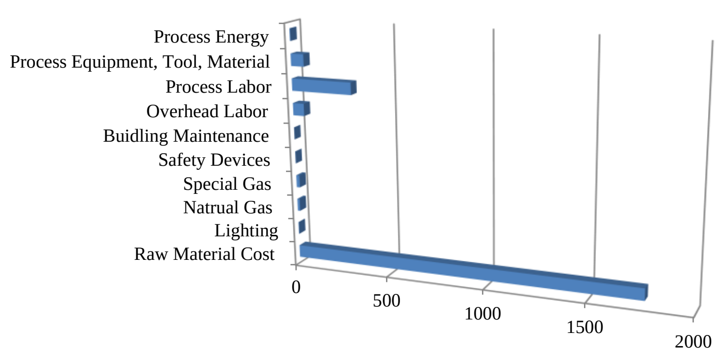
Shopfloor Level

The cost model shopfloor level structure consists raw material cost, lighting, gas consumption, special gas, safety device, building maintenance, overhead labor, process labor, Equipment, process energy. Exhibit 5 shows all the variables for shopfloor cost items.

Exhibit 5. Shopfloor Cost Model Structure Variables.

Cost Items	Variables	Definitons
Raw Material Cost	$C_{rawmaterial}$	Total raw material cost (from bill of material) for one unit of a product.
Lighting	$C_{lighting}$	Total lighting energy cost at the shopfloor, including both metal shop and assembly shop.
Natrual Gas	$C_{Naturalgas}$	Total natural gas cost
Special Gas	$C_{Specialgas}$	Total special gas cost, including, argon, N2, CO2, Oxygen, etc.
Safety Devices	$C_{Safetydevice}$	Safety device cost, e.g., eyewash, glasses, gloves, respirators, hearting protections.
Buidling Maintenance	$C_{Buildingmaintenance}$	Building maintenance cost, e.g., mat cleaning, sweep
Overhead Labor	$C_{Overheadlabor}$	Overhead labor includes part department workers, shopfloor helpers, one deburing operator, and one grinding operator.
Process Labor	$C_{Processlabor}$	Process labor include all the operators working on a specific process from punch to packaging
Process Equipment, Tool, Material	C_{PETM}	It includes equipment maintenance, process tools, and ancillary materials.
Process Energy	$C_{processenergy}$	Total energy consumption from each operation level process.

Exhibit 6. Model A shopfloor cost composition.



The shopfloor level structure includes some variables the values of which are aggregated by operation level variables. They are process labor ($C_{Processlabor}$), process equipment tool and material (C_{PETM}), and process energy ($C_{processenergy}$). Exhibit 6 shows the shopfloor structure cost composition for one unit of product model A.

The result shows that the total manufacturing (shopfloor) cost mainly comes from raw material which takes 78% of total cost. The labor cost which takes 14% of total cost, is the second largest amount contributing element, followed by process equipment tool and materials which takes about 3% of total cost.

Enterprise Level

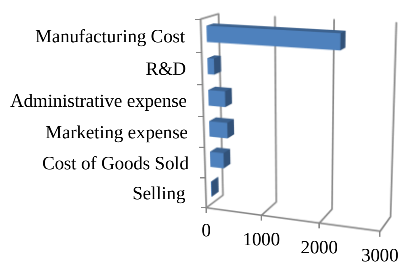
The cost model enterprise level structure consists selling, cost of goods sold, marketing expense, administrative expense, R&D, manufacturing cost, and other. Exhibit 7 shows all the variables for enterprise level structure.

Exhibit 7. Enterprise Level Cost Model Structure Variables.

Cost Items	**Variables**	**Definitons**
Selling	$C_{Selling}$	Selling costs include sales commissions, freight cost, sales tax, etc.
Cost of Goods Sold	$C_{Costofgoods}$	The direct costs attributable to the production of the goods sold by a company
Marketing expense	$C_{Marketing}$	The total cost associated with delivering goods or services to customers.
Administrative expense	$C_{Administration}$	Administrative costs are those state costs that cannot be identified with any single program (block) but are indispensable to the conduct of agency activities and to the organization's survival.
R&D	$C_{R\&D}$	Costs associated with research and design of new product development and technical support.
Manufacturing Cost	$C_{Manufacturing}$	Manufacturing cost is the sum of costs of all resources consumed in the process of making a product.

The manufacturing cost is the sum of shopfloor level costs. Exhibit 8 shows the enterprise level structure cost composition for one unit of product model A.

Exhibit 8. Model A enterprise level cost composition.



The result shows that manufacturing cost takes 69.01% of total cost of the company, followed by marketing expense, 10.08%, administrative expense 9.23%, cost of goods sold 7.6%, R&D 3.58%, and selling cost 0.41%.

Discussion

The systemic cost model proposed herein is to assist high mix low volume manufacturing company make strategic, production, and engineering decisions at three levels of the system, enterprise, shopfloor, and operation. The merit of this cost model structure is that it connects the three level decisions with reliable cost data that matters most to the company. This structure shows that operation level processing parameters will affect the shopfloor performance and even company's strategic decision. The case study described above implicates this fact. High mix low volume SMEs tend to have multiple setups for changeovers, which will increase the processing time and thus labor cost. Meanwhile, the nature of manufacturing determines raw material cost contributes most to the manufacturing cost. Therefore, reducing raw material use by redesign or standardize the products can be potential improvements for such manufacturers. Manufacturing cost can be greatly reduced with such improvements. It should be noted that such cost model not only functions as a tool to audit company cost on producing a product, but also serves as a preparation of gathering information to support further improvements (e.g., lean, sustainability). Projects can be identified based on the cost model results, and continuous improvement program can also be developed to support the long term goal. The limitation of this cost model is that it requires the company to make efforts to get detailed process information at operation level when they don't have installed real-time data collection system. Additionally, assumptions have to be made due to data availability.

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