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Impact of Work-In-Progress (WIP) Inventory Costs on Engineering Products Manufacturing Performance

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Abstract*—This research examines the critical impact of work-in-progress (WIP) inventory costs on engineering products manufacturing. As manufacturing organizations strive for operational excellence and competitive advantage, managing WIP inventory has emerged as a pivotal factor influencing production efficiency, cost effectiveness, and overall profitability. This study explores the conceptual foundations of WIP inventory and engineering products manufacturing, analyzes relevant theoretical frameworks including the Theory of Constraints and Just-in-Time manufacturing philosophy, and investigates the multifaceted effects of WIP costs on manufacturing performance. The study identifies four primary impact areas: production cycle time and throughput, working capital and financial performance, quality management and defect rates, plus space use and operational flexibility. Findings revealed excess WIP inventory incurs high carrying costs, locks up capital, heightens obsolescence risk, and conceals production issues. It concludes with actionable advice for manufacturers: measure systematically, adopt pull-based systems, boost visibility, and pursue continuous improvement to optimize WIP levels. This research contributes to the manufacturing management literature by providing a comprehensive analysis of WIP inventory dynamics and offering actionable strategies for engineering products manufacturers seeking to enhance operational performance and financial outcomes.

Keywords*— Work-In-Progress Inventory, WIP Costs, Engineering Manufacturing, Inventory Management, Theory of Constraints, Just-In-Time.

I. INTRODUCTION

The modern world of manufacturing is increasingly becoming dependent on the successful management of inventory in its effect on the success and sustainability of the organization. Work-in-progress (WIP) inventory is one of the most challenging and impactful components of the inventory that manufacturing firms have to deal with directly affecting the efficiency of their operations, financial performance, and positioning (Hopp and Spearman, 2011). WIP inventory management has its special challenges and opportunities to engineering products manufacturers, which normally face complex and multi-stage production processes of many components and assemblies.

Work-in-progress inventory comprises of all raw materials, parts, and sub-assemblies that are under different phases of the production cycle but are yet to be converted into finished goods (Stevenson, 2018). WIP inventory is in an intermediate form unlike raw materials that are waiting to be processed or a finished product that is ready to be distributed, it is a partially transformed input that has already utilized the manufacturing resources but has not yet brought in revenue. Such intermediate position also renders WIP inventory especially costly to hold and difficult to govern in an effective way (Jacobs and Chase, 2013).

The expenses of the WIP inventory are way beyond the mere storage costs. Such costs include the capital cost in materials and labor, inventory storage area, handling and movement costs, risk of spoilage or obsolescence, and the opportunity cost of the resources that could be used elsewhere (Bicheno and Holweg, 2016). These costs can run high and affect profitability to a great extent when manufacturers of engineering products are in the capital-intensive environment with the complicated production chains. It has been found that WIP inventory normally accounts 20-40 percent of the total inventory worth in manufacturing firms which makes it a significant part of working capital needs (Heizer, Render, and Munson, 2017).

The manufacturing of products that are engineered with complex designs, exquisite specifications and multi-phase fabrication and assembly processes has unique problems when it comes to the WIP inventory management. Engineering products like machinery, equipment, vehicles, industrial systems, and so forth often contain hundreds or thousands of parts, a number of work centers, variable processing times and multifaceted material flows (Slack, Brandon-Jones, and Johnston, 2016). This complexity opens up many possibilities of having a large stock between production processes, and this may result in an extreme level of WIP which overloads the production system.

The working cost of WIP inventory on the work of engineering products manufacturing has received more and more importance during the recent years when organizations are under pressure to cut down the costs, to increase their cash flow, to shorten the delivery time and enrich their operations. The increasing capital cost, the growing number of capital cost, global competition, and demands of customers create more demands on efficient inventory management practices (Christopher, 2016). Manufacturing entities that manage to reduce WIP inventory level and achieve the flow of production and delivery performance with other concurrent entities enjoy considerable competitive advantages regarding the cost structure, response time, and financial flexibility.

This research paper gives a detailed discussion of how the cost of WIP inventories affect the production of engineering products. The research creates conceptual and theoretical basis of understanding dynamics in the WIP inventories, analyses the mechanisms by which the WIP costs influence the manufacturing performance, and outlines the feasible strategies of improving the level of WIP. This article will help increase the knowledge of the WIP inventory management and help to make manufacturing performance better in engineering products industries by combining the knowledge about the operations management theory, manufacturing practice, and empirical research.

II. CONCEPTUAL FRAMEWORK

2.1 Defining Work-in-Progress (WIP) Inventory

Work-in-progress inventory, or work-in-process inventory, is the inventory that has already come to the manufacturing stage but was not turned into finished products that can be sold (Krajewski, Malhotra, and Ritzman, 2016). The category of inventory gets an important middle ground between the input of raw materials and output of finished products in a production flow. WIP inventory comprises of those items that are in progress of being worked on, items in between stages of production, partially completed sub-assemblies, and those products that are going through quality inspection or testing processes.

The theoretical knowledge of WIP inventory has a number of dimensions. To begin with, WIP reflects invested value that has yet to be converted to revenue or customer value through material expenses and value work but which has been accumulated (Russell and Taylor, 2014). Secondly, WIP acts as a buffer that decouples operations, allowing work centers to function more independently despite variations in processing times and capacities. Third, WIP represents apparent production system performance by showing that the cumulative level of it is frequently a sign of bottlenecks, inefficiencies, or disproportions within the manufacturing process (Goldratt and Cox, 2016).

WIP inventory cost elements contain several factors, which have cumulative effects on the economics of manufacturing. Carrying costs are costs involved with holding inventory within a time frame, which include capital costs the opportunity cost of the funds tied up in inventory, the cost involved with the physical space occupied by WIP, as well as insurance and taxes related to inventory values, and depreciation or obsolescence when products are old or outdated (Reid and Sanders, 2016). Handling costs arise from material transportation between production stages, labor for moving materials, equipment for material handling, and the risk of damage during transit. Also, WIP inventory creates administrative expenses in the form of tracking, control, and management of the inventory during the production process (Schroeder, Goldstein, and Rungtusanatham, 2013).

The level of WIP inventory expenditures may be considerable in the production of the engineering products. Research indicates that the carrying costs can be between 20 and 40 percent of the value of inventory in a year, which implies that a single dollar of WIP inventory will cost organizations twenty to forty cents a year to hold (Chopra and Meindl, 2016). To the manufacturers with high WIP, these costs are compounded to constitute significant financial burdens that directly cut the profitability levels and limit the financial flexibility. In addition to direct financial costs, heavy WIP inventory causes indirect costs in terms of less operational visibility, slower problem identification and detection, lower responsiveness to change, and complex production planning and control (Ohno, 1988).

2.2 Understanding Engineering Products Manufacturing

The process of engineering products manufacturing is the production of complex, technical-advanced products which demand specific design, engineering, and fabricating skills (Groover, 2015). This manufacturing group covers various industries such as machines production, equipment production, aerospace, automobiles, industrial systems, and precision tools. The engineering of products is usually characterized by highly-detailed designs, with close tolerances, a number of assemblies that have to be coordinated, highly-specialized materials and processes and a large amount of engineering content as compared to material content.

The nature of the engineering products production makes the process of operations unique and entails WIP inventory dynamics. Complexity of production is introduced by multi-level bills of materials, with hundreds or thousands of components, sequential and parallel production routes, interdependence between processing times of different operations, as well as quality requirements that necessitate precision and consistency (Black and Kohser, 2017). Process variability stems from diverse operations like machining, forming, welding, assembly, and finishing; equipment with varying capabilities and capacities; setup times between product variants; and quality inspection checkpoints throughout production.

In the engineering products manufacturing, the production environment is usually of either make-to-order or assemble-to-order types, with products being customized to customer requirements as opposed to being made in stock (Jacobs, Berry, Whybark, and Vollmann, 2011). This strategy requires the ability to have flexible production systems that manage variations of products, detailed production planning and scheduling to coordinate component availability, elaborate planning of material requirements to achieve timely procurement and fabrication, and close supervision of capacity to balance workload among production resources. These demands generate many chances in terms of WIP buildup since materials await processing, circulate among work centers, await the availability of components to be assembled or await quality inspection.

WIP management is also complicated by the consideration of lead time in case of engineering products production. The total manufacturing lead time also includes the queue time where the jobs wait to be processed, setup time whereby equipment is prepared, processing time whereby the actual production processes are done, waiting time where the material is moved and inspection time where the quality is checked (Monden, 2012). The real time of processing is 5-10% of total lead time in most engineering products manufacturing settings and the rest of 90-95% of the lead time is various types of waiting which translate directly to WIP inventory (Womack and Jones, 2003). Such phenomenon brings to light the significance of lead time minimization and WIP minimization since minimization of the non-value-adding waiting time also involves minimization of the inventory and the costs involved.

2.3 The Relationship Between WIP Costs and Manufacturing Performance

The theoretical connection between the cost of WIP inventories and the performance of manufacturing works occurs in a variety of mutually dependent processes. To begin with, WIP inventory has a financial cost that might be used in productive assets, market development, research and development or in value generating activities (Gaither and Frazier, 2002). The opportunity cost is especially important in the production of engineering products which are capital-intensive, where large quantities of working capital may be tied up in inventory. Second, WIP inventory hides the flaws in operations since the inventory offers buffers that conceal the problems of bottlenecks, quality defects and process inefficiencies (Shingo, 1989). By concealing the issues in the inventory buffers, organizations fail in the opportunities of improvement and they are left working with sub-optimal processes.

Third, WIP inventory leads to high production lead times because it adds to the queue time and congestion in the systems. Little Law is a relationship of the basic queuing theory, which illustrates that the average inventory equals the average throughput rate by the product of the average flow time (Hopp and Spearman, 2011). This mathematical correlation is because the lower the WIP inventory, the lower the lead time and hence faster customer response and better delivery performance. Fourth, a large amount of WIP inventory decreases the flexibility of operations by occupying production facilities, decreasing the capacity to adapt to changes, and escalating the burden of production planning and control (Schonberger, 2008).

The knowledge of these conceptual relationships forms the basis of determining the effects of WIP inventory costs on manufacturing engineering products as well as strategies to optimize it. In the next passages, theoretical frameworks are elaborated on, and particular impact mechanisms are analyzed in more detail.

III. THEORETICAL FRAMEWORK

3.1 Theory of Constraints

Theory of Constraints (TOC): this is a systematic methodology of enhancing organizational performance by solving the problems that reduce the amount of system throughput by determining and controlling constraints (Goldratt, 1990). Goldratt brought about TOC with his seminal work, The Goal, which took the manufacturing management concepts as a narrative that appealed to both the practitioners and academia. This theory was a result of the research carried by Goldratt on the creation of production scheduling software and the realization that the core approach to cost accounting in most cases caused counterproductive manufacturing decisions (Cox and Schleier, 2010).

The major principles of the Theory of Constraints have been based on a number of principles. To begin with, the performance of any given system must be constrained by at least something, and this constraint must be found and dealt with in case this system should be improved (Goldratt and Cox, 2016). physical constraints may include equipment capacity or managerial constraints which may include policies or practices. Second, organizations need to direct the improvement efforts to the constraints as opposed to non-constraints since the non-constraints do not get the overall system performance. Third, linking non-constraints to constraints will make the most of the system throughput to ensure bottleneck resources are put to maximum use (Dettmer, 2007). Fourth, it has five focusing steps that give a systematic methodology: find the constraint, leverage the constraint by maximising its productivity, subordinate everything else to the decisions made in step two, add more capacity as needed, and go back to step one to find the next constraint when the last constraint is violated (Rahman, 1998).

TOC presents the idea of the drum-buffer-rope scheduling, which entails the constraint acting as the drum that determines the speed of the production process, time buffers prevent the constraint by ensuring that something does not interfere with it, and rope systems ensure no material is released to the system exceeding the constraint capacity (Schragenheim and Dettmer, 2001). This method has a direct control of WIP inventory by stopping surplus material into production and building up before constraint. The theory underlines how surplus WIPs inventory is a surplus investment cost of not adding to throughput but at the carrying costs (Blackstone, 2001).

The strengths of the Theory of Constraints are that it has an intuitive logic, practitioners can easily follow it, does not aim at optimizing performance at a local level, but at the system-wide level, has practical tools and methodologies on how to implement the theory, has proven successful in various manufacturing settings, and clearly states the adverse effects of high levels of WIP inventory (Mabin and Balderstone, 2003). TOC has offered a unified approach that bridges the operational enhancement and financial outcomes, and is thus useful especially to engineering products manufacturers aiming at maximizing WIP levels.

The Theory of Constraints, however, has a number of criticisms and weaknesses. It has been criticized that TOC is excessively simplistic in handling such complex situations in manufacturing because it assumes just one constraint where a combination of many factors can be constraints at the same time (Spencer and Cox, 1995). In some competitive situations, the focus of the theory on throughput could underestimate the value of minimized costs and enhancement of quality. The implementation involves a lot of cultural change and management commitment which most organizations are unable to do. Also, the constraint emphasis of TOC can result in the neglecting of continuous improvement at non-constraint areas, and the organizations might be missing out on the opportunity to achieve gains incrementally (Gupta and Snyder, 2009).

In spite of such drawbacks, the Theory of Constraints can provide good insights in the field of engineering products manufacturing with regard to the effects of WIP inventory. Manufacturers are able to use this to focus improvement efforts on those operations that have been identified as bottlenecks and where they would exert the most significant effect on the operation of the system (Pegels and Watrous, 2005). The fact that TOC is explicitly concerned with the reduction of lead time and WIP inventory corresponds to the goal of reducing inventory costs. The drum-buffer-rope scheduling system gives realistic mechanisms of managing the level of WIP across the production system. TOC can provide a methodical way of defining the accumulation of WIP, the reasons as to why accumulation occurs, and a specific solution to this accumulation, in the case of engineering products manufacturers that have complex and multi-stage production processes, to achieve an improved throughput performance (or maintain) without increasing inventory levels (Boyd and Gupta, 2004).

3.2 Just-in-Time Manufacturing Philosophy

Just-in-Time (JIT) manufacturing originated, primarily by Toyota Motor Corporation in Japan in the 1950s-1970s, is an extensive philosophy of production, an attempt to remove waste and constantly make operations more efficient (Monden, 2012). Taiichi Ohno, commonly regarded as the main designer of JIT, came up with the system due to the availability of resources available after the war which could only be used with high efficiency (Ohno, 1988). The JIT philosophy later received global interest in the 1980s when western manufacturers attempted to learn the competitive strengths of the Japanese in terms of quality and productivity.

The main principles of Just-in-Time production are the removal of waste and continuous improvement. JIT establishes waste as any activity which consumes resources and fails to add value to the customer such as overproduction, waiting time, transportation, unsuitable processing, unnecessary inventory, unnecessary motion and defect (Liker, 2004). This philosophy emphasizes producing the right quantity at the right time to meet actual demand, rather than forecasted demand. JIT systems also drag production according to how it is used instead of pushing the materials in production according to schedules (Monden, 2012). Kanban system is a visual signaling system and it is used to coordinate the flow of materials by only allowing production and movement when it is necessary to the downstream processes.

Some of the key concepts behind JIT are continuous flow production, in which all products flow continuously through the production line with minimal interruption, takt time matching the pace of production to customer requirements, small batch production, which involves quick changeover techniques, total quality control that ensures the prevention of defects and employee participation in the continuous improvement effort (Womack, Jones, and Roos, 2007). JIT perceives inventory, especially WIP inventory as a wastage since it conceals defects, wastes resources, leads to longer lead time and is an overproduction (Shingo, 1989).

The advantages of the Just-in-Time manufacturing are great and properly written down. JIT dramatically lowers the levels of inventory in the supply chain, which directly lowers the carrying costs and liberates the working capital (Vonderembse and White, 2013). JIT is faster at problem-solving and process improvement by revealing issues that were previously covered by stock safety. There is also a tendency to increase the quality of products since defects are easily noticed and have to be addressed instead of propagating. When the batch size reduces and the flow increases, lead times are reduced, and responsiveness to customers is realized. Space needs decrease with less inventory and culture of the organization tends to be enhanced by more involvement of employees and empowerment (White and Prybutok, 2001).

Nevertheless, Just-in-Time manufacture too suffers criticism and flaws that narrow its use in some situations. JIT systems are susceptible to issues of disrupted supply chains due to low inventory as there is low buffer capability against unforeseen issues (Fullerton, McWatters, and Fawson, 2003). It involves many efforts in terms of supplier development and coordination that is hard to realize within a certain industry or region. Its philosophy requires very dependable processes and equipment that would require the investment of a lot of funds in maintenance and quality systems. Implementation may be slowed down due to cultural resistance especially in those organizations that have a conventional batch and queue attitude towards production (White, Pearson, and Wilson, 1999). Also, JIT is not always the best with all types of products, especially those products whose demand is unpredictable or whose production lead time is long.

Regardless of these shortcomings, Just-in-Time philosophy offers important tips in the process of controlling WIP inventory expenses in the manufacturing of engineering products. The underlying assumption of JIT that waste in inventory must be eradicated systematically directly relates to the subject of the research WIP cost effects (Inman and Mehra, 1991). The pull-based production system will avoid too much WIP build-up by making materials available in production when they are required. Continuous flow principles minimize the time in queues and congestion of the system resulting in less WIP. The small batch sizes facilitated by quick changeover methods allow less WIP between operations. To the manufacturers of engineering products, JIT principles can be viewed as viable measures to minimize the WIP inventory and at the same time enhance quality, lead time and operational efficiency (Claycomb, Germain, and Dröge, 1999). The focus of the philosophy towards inventory visibility that can be achieved by reducing inventory gives a strong justification to reducing WIP regardless of the operational constraints that this can cause.

IV. THE IMPACT OF WIP INVENTORY COSTS ON PRODUCTION CYCLE TIME AND THROUGHPUT

Work-in-progress inventory expenses have far reaching impacts on the production cycle-time and manufacturing, which develops a complicated dynamics that has significant impacts on the operational performance of the process of engineering products manufacturing. Time cycle of production, which is simply the summation of the time it takes to convert raw materials into final products is a very important competitive dimension because customers are demanding a reduction in delivery time and also increased responsiveness (Chase, Jacobs, and Aquilano, 2006). The rate at which the manufacturing system produces finished products is called throughput and it is directly related to the generation capacity of revenue and profitability required.

The correlation between WIP inventory and cycle time works with the queuing dynamics that exist in the Little Law that says that average inventory equals average throughput times the average cycle time (Hopp and Spearman, 2011). Mathematically, such relationship implies that a decrease in WIP inventory will inevitably decrease throughput by a constant percentage, or an increase in throughput by a constant percentage. In real world manufacturing situations too much WIP inventory adds to cycle time by introducing queues in work centers, where the jobs would be waiting to be processed. WIP builds up and increases queue times making total cycle time a very long way beyond processing time (Factory Physics, 2008).

The manufacture of engineering products is the area where the cycle time is usually subjected to a huge increment because of WIP build-up. Literature has shown that most manufacturing systems have little value adding processing time taking 5-15 percent of the total cycle time with the rest 85-95 percent of the time spent in forms of waiting (Womack and Jones, 2003). This phenomenon is due to the fact that goods are placed in work centers until there is capacity, are held between two production stages until the previous prerequisite components have been completed before the start of assembly and are held between two production stages until quality inspection is made. Every waiting adds WIP inventory and does not add value to the cycle time.

The expenses, which are involved in long cycle time, are high and complex. Increased cycle times slow down the generation of revenues, which prolongs the time interval between buying materials and payment of customers and thus elevates the working capitals needs and decreases cash flow (Corbett, 2006). Long cycles cause poor forecasting since with a long lead time a lot of uncertainty exists as to what is going to happen in future. The customers are subjected to longer delivery time, which may lead to loss of orders due to competitors with great speed. Also, the longer cycles put the risk of design changes, specification change or market shifts during the production period thus making the WIP inventory outdated (Deane, Craighead, and Ragsdale, 2009).

WIP inventory levels directly affect manufacturing throughput by influencing system capacity utilization and efficiency. Excessively high WIP can actually reduce throughput in several ways. To begin with, a large WIP situation causes blockage that slows the movement of materials and slows down the speed of production (Schmenner and Swink, 1998). Employees use greater amounts of time in locating materials, transporting inventory and dealing with complexity instead of undertaking value-added functions. Second, long WIP confuses priorities and does not make the most effective decisions on the order in which to handle jobs, which results in underutilization of capacity. Third, the quality issues are compounded when faulty products are not spotted in high WIP stock and later on they have to be reworked, which occupies the production facilities (Deane and Womack, 2003).

The implications of WIP costs to the cycle time and throughput of the product engineering manufacturers are represented in a particular operational challenge. Multi-parts products are complex products with many components providing numerous possibilities of WIP accumulation during the assembly phases when half-finished products await the arrival of the missing parts (Graves, 2011). Changes in lead time in making components lead to synchronization issues and this raises WIP buffers. The policies of batch production designed to optimize the use of equipment can result in large WIP levels between operations due to the batch size being larger than the immediate requirement in the downstream (Spearman, Woodruff, and Hopp, 1990). All of these dynamics increase the cycle times and constrain the throughput, which directly affects the competitive performance.

On the other hand, minimizing WIP inventory by improving flow and increasing synchronization can significantly enhance cycle time and throughput. Research indicates that targeted WIP reduction programs can be used to reduce cycle times by 50-80 percent and hold throughput constant or increase it (Blackburn, 1991). These enhancements create a high competitive advantage based on the ability to respond to customer orders faster, lower lead times bids that lead to increased business, better forecast accuracy as a result of shorter planning horizons, and increased flexibility to respond to design changes or specification changes (Stalk and Hout, 1990). The financial advantages are lower working capital, faster cash flow, less risk of obsolescence, and better profitability because of the higher throughput and lesser carrying costs.

V. THE EFFECT OF WIP INVENTORY COSTS ON WORKING CAPITAL AND FINANCIAL PERFORMANCE

The cost of work-in-progress inventory has a huge impact on the working capital requirements and financial performance as a whole, that poses major economic implications on the engineering products manufacturers. The definition of working capital is a difference between current assets and current liabilities; it is the amounts of finances needed to sustain the operations (Brigham and Ehrhardt, 2013). The inventory and WIP as a significant part of current assets in a manufacturing organization generally influence the levels of working capital and the cost thereof.

The economic cost of WIP inventory, will start with the direct capital buyer of the raw material and payment of labor to process the activities. This is especially so in engineering products manufacturing, where production periods can range between weeks and months and the large amount of money is bound in WIP inventory before products can be finished and sold (Gaur, Fisher, and Raman, 2005). The opportunity cost is the invested capital that is equivalent to the returns that would be accrued in case the funds were invested in other places. The opportunity cost of inventory of excess WIP at common cost of capital of 10-20 percent per year is a huge recurring cost that lowers profitability (Stewart, 2013).

In addition to direct capital costs, the WIP inventory creates numerous classes of carrying costs compounding as time goes by. Storage expenses are the area needed to store WIP inventory which in manufacturing plants sells at a high price owing to the closeness to the production areas (Pyke and Cohen, 1993). The insurance value is also high when there is a high value of the inventory since manufacturers need to secure it against loss or damage. Inventory value is used to calculate property taxes in a lot of jurisdictions, leading to more holding expenses. Depreciation and obsolescence is also a major risk as the WIP inventory grows old especially in a sector where products designs keep changing at high rates or where there is a frequent change in engineering (Song and Zipkin, 2003). The total cost of carrying cost would include handling materials to transfer WIP among work centers, to count and track inventory, to store and retrieve materials.

The studies on inventory carrying costs propose that the overall annual costs are usually between 20 and 40 percent of inventory value with most of the engineering products manufacturers falling on the upper end of this range because of the complexity of their products and longer production cycles (Ballou, 2004). This implies that in every dollar of WIP stocks, manufacturers spend twenty to forty cents every year to maintain the same. These carrying costs in organizations where the WIP inventory is worth millions or tens of millions of dollars are very high continuing expenses that directly lower net income and return on assets (Koumanakos, 2008).

Effects of excess WIP inventory on financial statements are felt on a variety of levels. High WIP inventory inflates current assets which is a positive balance sheet statement, but in reality, it is inefficient asset usage (Capkun, Hameri, and Weiss, 2009). One of the major measures of profitability, which is known as return on assets (ROA) declines as the asset base swells without the equivalent rise in profits. The number of days inventory outstanding (DIO) is a calculation of the length of time that the capital has been on inventory and this indicates the more working capital is on the WIPs and the less efficient working capital management is (Deloof, 2003).

Effects of income statement are also important. Carrying costs would directly affect operating income by raising the expenses. In the case where the design changes, or modifications in specifications, or changes in market conditions leads to the obsolescence of WIP inventory, the write-offs or write-downs lead to underreporting of profits and can potentially have an impact on stock prices of publicly traded companies (Chen, Frank, and Wu, 2005). Reduced profitability rates due to inventory costs undermine the competitive positioning and can lead to price increases which can lose market share or reduction of volumes which spread up fixed costs across fewer units.

Specific attention should be given to cash flow implications, insufficient cash flow is one of the major factors leading to business failure, despite the profitable nature of a business (Richards and Laughlin, 1980). The time that cash takes to turn over cash to cash is the cash-to-cash cycle time that is calculated by the duration it takes to pay the supplier and collect cash with the customers, longer production cycles increase the cash-to-cash cycle (Farris and Hutchison, 2002). Prolonged cash cycles compound the need to borrow and interest costs, which add greater strains on financial performance. In the case of engineering products manufacturers with long production lead times, the cash flow management and retained production capacity would be a burning issue that the level of WIP inventory would have a direct impact on.

The connection between WIP inventory and financial performance has been empirically proved in a number of studies. A study conducted by Gaur et al. (2005) established high negative associations between the level of inventory and gross margins, indicating that high inventory levels lower profitability. The study by Capkun et al. (2009) proved that the reduction of the inventory has positive effects on the performance of the operations and market value. These results support theoretical assumptions that lowering WIP inventory results in better financial performance in terms of lowering carrying costs, increasing rates of cash turnover, and better use of assets.

To engineering products manufactures, WIP inventory management is financially related to strategic considerations such as competitive positioning, growth capacity as well as financial flexibility. Companies that have less WIP inventory in their system release working capital that may be used in developing its products or increasing its capacity or expanding its market (Eroglu and Hofer, 2011). Lower inventory carrying costs will be turned into more competitive cost structures such that aggressive prices or increased margins can be realized. More immediate cash conversion enhances financial flexibility and decreases reliance on external funding, decreasing financial risk and raising strategic choices. These benefits generate compounding benefits that would place low-WIP manufacturers into a better long-term performance.

VI. WIP INVENTORY COSTS AND QUALITY MANAGEMENT IN MANUFACTURING

The interplay between WIP inventory costs and quality management creates a paradoxical dynamic: excessive WIP masks quality issues, inflates quality costs, and severely undermines manufacturing performance for engineering products. Quality management involves any process that is aimed at avoiding defects, identification of nonconformities, and the provision of specifications on the products and customer requirements (Juran and Godfrey, 1999). In contemporary production, quality has been transformed to preventive-based systems that incorporate quality in the manufacturing processes as opposed to finding defects once they have taken place.

High levels of WIP inventory will compromise the effectiveness of quality management in a number of ways. To begin with, high levels of WIP cause delays in identifying problems as they give time lags between the formation of defects and their discovery (Shingo, 1989). When the process steps have large inventories, the defective ones will not be detected until a large amount of more units are manufactured, escalating the extent and the price of quality issues. As an illustration, when a machining process starts producing parts that are out of specifications and the error is not detected until the assembly process several days or weeks later, hundreds or thousands of bad parts may have been made in the meantime (Gryna, 2001). Second, WIP inventory makes root cause analysis and corrective action hard since the relationship between causes and effects is obscured. When the defects are revealed many days after the manufacturing process, it becomes highly challenging to determine what settings of the machine, the states of the tools, the batches of materials, or the activities of the workers predisposed the issues (Montgomery, 2012). Such a detective activity postpones the taking of corrective measures and creates the risk of the repetition of problems. Third, large WIP inventories produce sorting and rework overheads in case defects are realized because manufacturers have to determine which inventory units are impacted, isolate defective units, and either repair or dispose of nonconformal products (Evans and Lindsay, 2014).

Excess WIP inventory imposes high, multidimensional costs on quality. It amplifies internal failure costs defects caught before customer delivery proportional to WIP volume.

Scrap costs multiply as defective products consume resources and labour only to be discarded. Rework costs rise with more units needing correction, tying up capacity and resources. Downgrading costs occur when defective products must be sold below their true value. The retest and reinspection demands would also be high since the items that had been reworked have to be re-verified (Juran and Godfrey, 1999).

The external failure costs, which are defects that find their way to the customers also escalate with WIP inventory via subtle mechanisms. Long lead times due to large WIP inventory, requires manufacturers to ship goods immediately when they are finished to satisfy the delivery promises, which might compromise rigor in final inspection (Dale and Plunkett, 2017). Also quality issues that go unnoticed with such large WIP inventories may not be identified until customers receive their products and then warranty fees, customer complaint, returns and damaged reputation costs are accrued, which greatly exceed internal failure costs.

The quality implications of WIP inventory become acute especially in the case of manufacturing engineering products, where the products tend to be fairly complex assemblies with many components and tight tolerances. Absent/wrong parts found in the assembly process stop the production process and cause more WIP stock since partially finished assemblies are kept waiting to obtain the correct parts (Graves, 2011). Early production issues can have a cascading effect across the manufacturing system since quality issues can not be identified until later in the production process when it is time to perform the assembly or testing process. Specifications are process-oriented, and provide feedback instantly, which is compromised by large WIP stocks through postponing the identification of problems (Black and Kohser, 2017).

On the other hand, lowering WIP inventory increases management efficacy of quality and lowers quality expenses by a variety of courses. Reduced WIP means quicker feedback loops correcting the deviations in the processes quicker and more units can be corrected before many are made defective (Monden, 2012). The high visibility of problems makes organizations work on the root cause instead of operating around the problems with inventory buffer systems. Smaller batch sizes attributed to the low WIP inventory imply that less inventory is impacted during the occurrence of issues, which restricts the area of quality incidents. The increased level of monitoring and control over the processes is more possible when the complexity of handling smaller quantities of WIP reduces (Liker, 2004).

Toyota Production System makes direct use of this relationship by actively minimizing inventory buffers in order to reveal quality issues and to compel a solution (Ohno, 1988). This method, which is also referred to as throwing the water down to reveal the rocks, relies on the WIP reduction as a quality improvement instrument. In the case of arising problems under caused by diminished buffers, it is up to the teams to find permanent solutions to the situation instead of making up with new inventory. With time, such a methodology produces solid processes that have low defect rates inherently (Womack and Jones, 2003).

Empirical studies embrace the relationship between inferior WIP inventory and excellent quality performance. The empirical literature on lean manufacturing applications always indicates that there are concomitant decreases in inventory and defect rates, which indicates that these two factors are complementary, not rivalrous (Shah and Ward, 2003). The organizations that manage to reduce WIP inventory are usually characterized by high quality level, reduction in quality costs and quality culture based on continuous improvement and focus on problem solving (Flynn, Sakakibara, and Schroeder, 1995). WIP inventory reduction is an effective quality improvement initiative enabler to engineering product manufacturers who need to gain a competitive edge by ensuring quality excellence.

VII. SPACE UTILIZATION, OPERATIONAL FLEXIBILITY, AND WIP INVENTORY COSTS

The costs of work-in-progress inventory are not limited to the financial carrying costs but also to the important consequences on the use of space and operational flexibility, which is of the essence in the manufacturing effectiveness and competitiveness of the engineering products manufacturing industries. The space in the manufacturing is a precious resource that is usually limited, and it has a direct impact on the efficiency of operations, layout optimization, and manufacturing capacity (Tompkins, White, Bozer, and Tanchoco, 2010). The operational flexibility, which is the ability to respond to changing events, product, quantity, or specifications, has become an important competitive ability in the dynamic market settings (Upton, 1994).

The WIP inventory is a significant operational and monetary drain to manufacturers of engineering products due to the consumption of space. WIP inventory takes up physical storage space that otherwise can be occupied by manufacturing equipments, production areas, quality inspection points, or other value-adding operations (Heragu, 2008). At limited space facilities excess WIP inventory could reduce capacity expansion possibilities, or impose suboptimal layout plans, or require costly facility extensions. The space of manufacturing can be quite a cost, especially in the industrialized areas with high real estate prices and the space that the inventory occupies can be a considerable expense that must be realized on a regular basis (Francis, McGinnis, and White, 2009).

In addition to the direct consumption of space, WIP inventory has indirect issues concerning space. The greater the inventory, the higher the material handling needs, which require aisles where forklifts will operate, staging zones where inventory will be transported, and material transport routes between work centers (Groover, 2015). Such needs also minimise the availability of productive space. The visual management and operational visibility is compromised since large WIP stocks would create sight lines across the manufacturing floor, thereby complicating supervision and decreasing the usefulness of visual control tools (Liker, 2004). Safety hazards can also be enhanced due to the hindrances formed by accumulated inventory, congestion, and even trip hazards that expose the workers to risks.

The effect of WIP inventory on operational flexibility is a rather significant issue to the engineering products manufacturers of the competitive markets. High levels of WIP inventory cause lack of flexibility in several ways. First, high levels of inventory decrease the agility in manufacturing since it will take more time to switch product mix, add new products or alter specifications to meet customer requirements (Jack and Raturi, 2002). With a significant WIP inventory of given products or configuration, manufacturers are pressurized to clear the inventory before moving to other products however the market conditions or customer needs have shifted.

Second, WIP inventory complicates production planning and scheduling because it adds complexity and material tracking, visibility and control of work-in-process and production (Hopp and Spearman, 2011). The more inventory a planner has, the harder it will be to make a production decision taking into consideration the current WIP inventory. When the value orders are filled with large WIP inventories that occupy the work centers and restrict the capacity availability, expediting the high-priority orders becomes difficult. The probability of generating obsolete inventory goes up with the WIP and especially in the engineering products where the design changes or the introduction of specifications take place frequently (Song and Zipkin, 2003).

Third, a large WIP inventory slows down financial flexibility as it maintains the working capital that is otherwise available to engage in other strategic activities (Richards and Laughlin, 1980). Offering a high amount of WIP, organizations have limited financial ability to undertake new equipment, new products, new market or react to competitive threats. It is a financial constraint that restricts the ability to make strategic choices and decreases the organizational flexibility. Fourth, there is organizational inertia due to high levels of WIP which creates a resistance to process changes or improvement initiatives that can cause disturbance to the prevailing inventory (Schonberger, 2008).

For engineering product manufacturers, WIP inventory creates space constraints and reduces operational flexibility, posing significant challenges. The space demand is needed in the storage of sub-assembly between production phases because complex products, which require several assembly stages, demand space (Groover, 2015). Machine, equipment, and industrial items have large parts that take up a considerable amount of space on the floor even when in small amounts. The customization demands common to made-to-order or engineered-to-order products require that production should be flexible to allow it to accommodate variation, yet too much WIP inventory becomes counterproductive to WIP flexibility by complicating it and decreasing responsiveness (Jacobs et al., 2011).

On the other hand, declining WIP inventory generates space and flexibility benefits to improve competitive performance. Reduced WIP levels release manufacturing floor space to be used in value-adding processes, such as extra production capacity to fuel growth, new layout layouts that minimize material handling and enhance flow, separate quality control areas that strengthen inspection processes, and continuous improvement space where teams can carry out problem-solving (Tompkins et al., 2010). Reclaimed space can eradicate or postpone the facility expansion requirement, that is, save significant capital outlays.

WIP reduction increases operational flexibility that allows responding to market changes and customer requirements more quickly. Companies that have low WIP inventory are able to change production mix faster, launch new products faster, specification of customers easier and volume changes easier (Jack and Raturi, 2002). These capabilities translate to competitive advantages such as shorter quoted lead times that is appealing to customers, capability to meet customer requirements which are demanding and need quick response, less exposure to obsolescence due to changes in the market or design and improved customer reputation of responsiveness and flexibility (Stalk and Hout, 1990).

Companies that can effectively reduce WIP inventory and maintain a production flow are able to simultaneously improve cost, quality, delivery and flexibility that are the key dimensions of operational performance (Schmenner and Swink, 1998). This is a multidimensional performance enhancement that generates sustainable competitive advantages that translate to top market positions and financial performance. For engineering product manufacturers where products are complex, customization is standard, and customer demands evolve constantly WIP reduction delivers critical space and flexibility gains as key enablers of strategic success.

VIII. CONCLUSIONS

This comprehensive examination of work-in-progress inventory costs in engineering products manufacturing reveals profound and multifaceted impacts that extend across operational, financial, and strategic dimensions of manufacturing performance. The research demonstrates that WIP inventory represents far more than a simple accounting category or operational buffer; rather, it constitutes a critical determinant of manufacturing effectiveness that influences production efficiency, cost competitiveness, quality outcomes, and organizational flexibility.

The conceptual and theoretical foundations established in this article provide clear frameworks for understanding WIP inventory dynamics. The Theory of Constraints illuminates how WIP accumulates at system bottlenecks and constrains overall throughput, while emphasizing that excess inventory represents investment that does not contribute to revenue generation. The Just-in-Time philosophy reinforces that WIP inventory constitutes waste that should be systematically eliminated to expose and resolve underlying operational problems. Together, these theoretical perspectives establish that minimizing WIP inventory while maintaining production flow represents a fundamental objective for manufacturing excellence.

Analysis of specific impact mechanisms shows that WIP inventory costs arise through extended production cycle times and reduced throughput, high working capital demands vis-a-vis financial performance, quality management challenges with elevated quality costs, and space consumption that limits operational flexibility. Each area delivers tangible economic losses, eroding competitiveness and profitability. The cumulative effect of these impacts suggests that excessive WIP inventory imposes costs far exceeding simple carrying expense calculations, with hidden costs often surpassing visible ones.

For engineering products manufacturers, the WIP inventory challenge is particularly acute due to production complexity, product customization, multiple production stages, and extended lead times that characterize these operations. The research indicates that many engineering products manufacturers operate with WIP levels substantially higher than necessary to maintain production flow, representing significant opportunities for improvement. Organizations that successfully reduce WIP inventory while maintaining or improving throughput achieve substantial competitive advantages through improved cost structures, faster customer response, enhanced quality outcomes, and greater operational flexibility.

The findings underscore that WIP inventory reduction should not be viewed as merely a cost-cutting initiative but rather as a comprehensive improvement strategy that drives performance enhancement across multiple dimensions. Reducing WIP inventory forces organizations to address fundamental operational issues including bottleneck management, quality improvement, setup time reduction, and production flow enhancement. The problem-solving and process improvement stimulated by WIP reduction efforts generate benefits that extend far beyond inventory cost savings.

An important conclusion emerging from this analysis is that WIP inventory management requires integrated approaches that address root causes rather than symptoms. Simply reducing inventory without improving underlying processes creates production disruptions and delivery failures that ultimately prove counterproductive. Successful WIP reduction requires systematic attention to capacity balancing, quality assurance, setup time reduction, production scheduling, and supplier coordination. Organizations must build operational capabilities that enable low-inventory operations rather than merely mandating inventory reductions.

The research also highlights that WIP inventory levels reflect management decisions about production policies, performance metrics, and operational priorities. Traditional metrics emphasizing equipment utilization, absorption costing, and batch size optimization often inadvertently encourage excess WIP accumulation. Transitioning to metrics that emphasize flow, throughput, and inventory turns requires fundamental shifts in management philosophy and performance measurement systems. Organizations serious about WIP reduction must align their metrics, incentives, and cultural norms with low-inventory objectives.

Looking forward, the importance of WIP inventory management will likely intensify as manufacturing environments become more dynamic, product life cycles shorten, customization increases, and competitive pressures mount. Engineering products manufacturers that develop distinctive capabilities in managing WIP inventory will position themselves for sustained competitive advantage. Conversely, organizations that tolerate excessive WIP inventory will find themselves at increasing disadvantage in cost competitiveness, delivery performance, quality outcomes, and operational flexibility.

IX. RECOMMENDATIONS

Based on the comprehensive analysis of WIP inventory cost impacts on engineering products manufacturing, this research offers the following recommendations for manufacturing organizations seeking to optimize WIP levels and enhance operational performance.

1. Establish Comprehensive WIP Measurement and Monitoring Systems: Manufacturing organizations should implement systematic approaches to measuring and monitoring WIP inventory levels, locations, and ages throughout the production system. This recommendation includes developing metrics that track WIP inventory by value, quantity, and days of supply at each production stage; implementing visual management systems that make WIP levels immediately visible to operations personnel and management; establishing inventory tracking technologies such as barcode or RFID systems that provide real-time visibility into inventory locations and movement; and creating regular reporting mechanisms that communicate WIP performance to stakeholders and trigger corrective actions when levels exceed targets. Effective measurement provides the foundation for improvement by establishing baseline performance, identifying problem areas, tracking progress, and maintaining accountability (Hopp and Spearman, 2011).
2. Implement Pull-Based Production Systems: Organizations should transition from push-based production scheduling to pull-based systems that authorize production only in response to actual demand signals. This recommendation encompasses implementing kanban systems or other visual pull mechanisms that limit WIP accumulation between production stages; establishing work authorization processes that prevent work centers from producing unless downstream operations signal readiness to accept output; defining maximum WIP limits for each production stage based on analysis of optimal inventory levels; and developing production scheduling approaches that synchronize material release with actual consumption rates rather than forecasted requirements (Monden, 2012). Pull systems fundamentally prevent WIP accumulation by limiting what can be produced rather than maximizing what could be produced.
3. Identify and Manage System Constraints: Manufacturers should use Theory of Constraints principles to pinpoint bottleneck operations where WIP accumulates, then target improvement initiatives at these constraint resources. Specific actions include conducting capacity analysis to identify which work centers limit overall system throughput; implementing protective buffers immediately before constraints to ensure maximum utilization of bottleneck resources; subordinating non-constraint

operations to constraint scheduling to prevent excess WIP accumulation ahead of bottlenecks; investing in constraint elevation through capacity additions, efficiency improvements, or outsourcing when justified by throughput benefits; and regularly reassessing constraint locations as improvements shift bottlenecks to different operations (Goldratt, 1990). Constraint-focused management ensures that improvement efforts concentrate where they will generate maximum system-wide benefits.

4. Reduce Batch Sizes and Setup Times: Engineering products manufacturers should systematically reduce production batch sizes and setup times to enable smaller lot production with reduced WIP inventory. This recommendation includes conducting setup time analysis to identify components of changeover processes and opportunities for reduction; implementing single-minute exchange of die (SMED) techniques that convert internal setup activities to external activities performed while equipment operates; standardizing setups across similar equipment to reduce complexity and variability; training operators in quick changeover procedures and creating incentives for continuous improvement; and gradually reducing batch sizes as setup improvements make smaller lots economically feasible (Shingo, 1989). Smaller batches directly reduce WIP inventory while improving flexibility and reducing lead times.
5. Enhance Quality at Source and Problem-Solving Capabilities: Organizations should build quality into production processes rather than relying on inspection to detect defects, thereby enabling WIP reduction without quality deterioration. Recommended actions include implementing error-proofing (poka-yoke) devices that prevent defects from occurring; establishing in-process quality checks that detect problems immediately after production; training workers in problem-solving methodologies and empowering them to stop production when problems occur; implementing total productive maintenance programs that ensure equipment reliability and reduce breakdowns; and creating quality metrics that emphasize prevention and first-time-through quality rather than detection and sorting (Liker, 2004). Quality at source enables WIP reduction by ensuring that defective items do not propagate through the production system.
6. Improve Production Flow and Layout: Manufacturers should optimize production layouts and material flows to minimize transportation, handling, and queuing that generate WIP accumulation. Specific recommendations include analyzing material flow patterns and redesigning layouts to minimize distances and handling; implementing cellular manufacturing arrangements that group operations for product families; locating sequential operations in close proximity to reduce transportation time and inventory; eliminating barriers and obstacles that impede smooth material flow; and creating U-shaped cells or continuous flow lines that facilitate communication and coordination among operations (Black and Kohser, 2017). Improved flow reduces the need for WIP inventory buffers while accelerating throughput.
7. Develop Supplier Integration and Coordination: For engineering products manufacturers dependent on purchased components, reducing WIP inventory requires close coordination with suppliers to ensure reliable, timely deliveries. Recommended actions include establishing long-term relationships with key suppliers based on trust and mutual benefit; sharing production schedules and demand forecasts to enable supplier planning; implementing vendor-managed inventory or consignment arrangements that reduce inventory ownership; developing supplier quality certification programs that ensure incoming

material reliability; and creating communication channels that enable rapid problem resolution and continuous improvement (Christopher, 2016). Supplier integration extends lean principles beyond company boundaries to reduce WIP throughout the supply chain.

8. Align Performance Metrics and Incentives with WIP Reduction Objectives: Organizations should revise performance measurement systems to emphasize metrics that encourage low WIP inventory rather than metrics that inadvertently promote accumulation. This recommendation includes replacing equipment utilization metrics with throughput and inventory turn metrics; emphasizing total system performance rather than individual work center efficiency; measuring and rewarding cycle time reduction and on-time delivery performance; tracking inventory days of supply as a key operational metric; and creating incentive systems that reward teams for WIP reduction achievements (Corbett, 2006). Aligned metrics ensure that operational decisions support rather than undermine inventory reduction objectives.
9. Invest in Training and Cultural Change: Successful WIP inventory reduction requires significant cultural transformation and capability building throughout the organization. Recommendations include providing comprehensive training in lean manufacturing principles and WIP management concepts; engaging employees at all levels in continuous improvement initiatives focused on inventory reduction; celebrating successes and recognizing teams that achieve inventory reduction milestones; creating cross-functional teams that address systemic issues contributing to WIP accumulation; and demonstrating sustained management commitment to inventory reduction as a strategic priority (Liker, 2004). Cultural alignment ensures that inventory reduction initiatives receive the organizational support necessary for sustained success.
10. Pursue Continuous Improvement in WIP Management: Finally, organizations should recognize that WIP optimization is not a one-time project but an ongoing journey requiring continuous attention and improvement. This recommendation encompasses establishing regular WIP review processes that assess performance and identify opportunities; benchmarking against industry best practices and competitors; experimenting with incremental reductions in WIP buffers to test system capabilities; learning from both successes and failures in inventory reduction initiatives; and maintaining leadership focus on inventory management as a competitive priority (Schonberger, 2008). Continuous improvement ensures that organizations build on initial gains and sustain competitive advantages from superior WIP management.
11. Implement these recommendations via a phased approach: start with measurement and analysis, advance to pilot projects that prove benefits and build skills, then scale successes across the manufacturing system. Anticipate challenges and setbacks, but stay focused on the major operational and financial gains from WIP reduction. Engineering product manufacturers adopting these successfully will gain competitiveness through lower costs, quicker customer response, superior quality, and greater flexibility.

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