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CUTTING STOCK DILEMMA IN MANUFACTURING SUPPLY SYSTEMS

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Abstract: During conventional manufacturing processes the supply of raw material is straightforward: the raw material is supplied to the workstation based on a predefined bill of material or some kind of a supply mechanism like Kanban and the manufacturing cost is calculated based on the registered consumption. Laser cutting, shearing, and bar stock machining are widely applied in sheet metal and bar stick material processing. These technologies make high precision, repeatability, and flexibility possible. However when applying these technologies it can be challenging to keep accurate material consumption records in enterprise resource planning (ERP) systems. There is a major difference how the materials (sheet metal, bar stock) are allocated to the manufacturing task, whether the whole unit is allocated or only a proportion of the unit based on a predefined or estimated norm. The core problem lies in how the residual material is handled after cutting: whether it should be immediately allocated as fully consumed during production, or whether it can be reclassified as reusable inventory for future manufacturing operations. The uncertainty of the usability of these remnants naturally causes problems in project cost calculations, and potential retrospective active corrections. The above described well known problem is still considered as a major decision-making problem when establishing the logic of material handling systems. This paper explores the theoretical and practical dimensions of this issue, including the material allocation dilemma, energy and resource implications and potential technological solutions. The discussion extends to both sheet materials and bar stock, as they pose similar but context-specific challenges.

Keywords: Cutting stock problem, Manufacturing supply, Metal sheel manufacturing, Bar stock manufacturing, Residual material management

INTRODUCTION

Material efficiency has long been a cornerstone of industrial production. In high-volume and high-precision industries such as automotive, aerospace, and metal fabrication, the cost of raw material frequently represents one of the largest components of total manufacturing expenses. With the growing emphasis on sustainability, minimizing material waste is not only an economic imperative but also an environmental responsibility.

Laser cutting has emerged as a key technology for sheet processing due to its superior precision, narrow kerf width, and reduced waste compared to conventional mechanical cutting methods. Similarly, shearing is often used for rapid separation of sheet materials. Bar stock machining (including cutting rods, tubes, and profiles to length) is also a similar raw material preparation problem, the key difference is that the metrics for optimization is not area but length. Across all these processes, a recurring challenge emerges, namely how to correctly account for and manage the remnants of raw materials.

THE MATERIAL COST ALLOCATION DILEMMA

The cutting stock problem is a widely researched topic among industry experts and researchers. A recent review by Senergues et al. [1] provides a comprehensive overview of

approaches to the cutting stock problem with usable leftovers, highlighting major modeling techniques and solution strategies. Ma et al. [2] Extend the problem to a two-dimensional setting with flexible length and usable leftovers, proposing formulations that address multiple objectives.

Benjaoran and Bhokha [3] developed a three-step solution approach for the cutting stock problem in the context of construction steel, aiming to minimize trim loss and stock usage.

Silva et al. [4] analyze the one-dimensional multi-period cutting stock problem with setup costs, offering new formulations and theoretical insights.

Nascimento et al [5] investigate a two-dimensional cutting stock problem variant that incorporates demand uncertainty and usable leftovers.

In current industrial practice two main accounting approaches exist:

- Full Consumption Registration means that the entire raw material unit—whether a sheet or a bar—is recorded as fully consumed once it enters a production order. This approach greatly simplifies accounting and eliminates uncertainty at the expense of overestimating material consumption if significant remnants remain.

— In case of Residual Deduction, the consumed quantity is calculated by subtracting the leftover portion from the initial stock. This requires precise measurement, classification, storage, and inventory tracking of residual materials. While this method increases accuracy, it introduces additional overhead in terms of labor, energy, and data management.

The dilemma lies in the fact that, at the time of post-calculation (i.e., immediately after production), the actual usability of the residual material is unknown. Residual sheets or bar segments may or may not be applicable in future jobs, depending on dimensions, tolerances, and production schedules. Only once the remnant is reused can its status as reusable inventory be validated, potentially necessitating a retroactive correction of the initial cost calculation. This temporal gap between production and certainty creates systemic inaccuracies.

MATHEMATICAL MODELS OF MATERIAL CONSUMPTION

For sheet materials, net consumption can be represented by a widely used standard equation:

$$C_{\text{sheet}} = A_{\text{total}} - A_{\text{residual}} = \mu \sum_{i \in P} q_i a_i$$

$$= (1 + l) \sum_{i \in P} q_i a_i$$

where:

C_{sheet} : consumed area,

A_{total} : initial sheet area,

A_{residual} : area of the leftover material,

P : the set of part types produced from the sheet,

q_i : number of parts of type i ,

a_i : net CAD area of a single part i ,

$\mu \geq 1$: the loss multiplier, applied to account for real-world inefficiencies such as: kerf (cut width), lead-ins and lead-outs, piercing, micro-joints, overburn, nesting/trim waste.

$l = \mu - 1$: the loss ratio, expressed as a fraction of the ideal material area.

For bar stock materials, a length-based model is appropriate:

$$C_{\text{bar}} = L_{\text{total}} - L_{\text{residual}} = (L_{\text{cut}} - L_{\text{loss}}) \times n$$

where:

C_{bar} : consumed length,

L_{total} : initial bar length,

L_{residual} : leftover segment.

L_{cut} = required cut length,

L_{loss} = loss per cut (e.g., saw blade kerf or laser width),

n : number of pieces cut.

This formula highlights how small per-cut losses accumulate significantly in high-volume operations.

SUSTAINABILITY ISSUES AND RESOURCE REQUIREMENTS

Residual material management implies sustainability aspects as well [6], [7]. Residual material management requires not only physical storage space but also systematic processes for classification, labelling, and retrieval. For sheets, irregularly shaped offcuts may be difficult to store and inefficient to reuse. For bars and rods, remnants often become too short to serve future production, despite having measurable material value. Each handling step consumes energy—whether in the form of human labour, machine operation, or logistics. In many cases, the energy and storage costs outweigh the potential savings from remnant reuse, especially if the residual material eventually becomes scrap.

Moreover, digital tracking systems, such as barcode or RFID labelling, can mitigate these challenges but add implementation and maintenance costs. Thus, manufacturers must balance between accounting accuracy, operational simplicity, and economic feasibility.

POST-CALCULATION MISTAKES

Calculation is central issue is the timing of reliable knowledge. During immediate post-calculation, the system must decide whether to register the entire raw material as consumed or deduct the remnant. However, the future usability of that remnant remains uncertain:

— If recorded as fully consumed: Later reuse requires retroactive correction of cost data of current project. A better solution is that the proportional material cost is reallocated from the current project to the future project.

— If recorded as partially consumed: Later realization that the remnant is unusable leads to understated costs of current project.

This causes errors in financial planning, performance evaluation, and profit analysis. The issue If the specific industry has fluctuating demand patterns, where remnants may remain unused for long periods the size of the problem is even larger. Hooshmand et al. [8] adopts a parametric cost-modelling approach in engineer-to-order manufacturing, enabling early cost estimates with 10–15 % accuracy and performing post-production profitability check and refines future estimates.

The following schematic illustrates the decision-making dilemma for both sheet and bar stock materials:

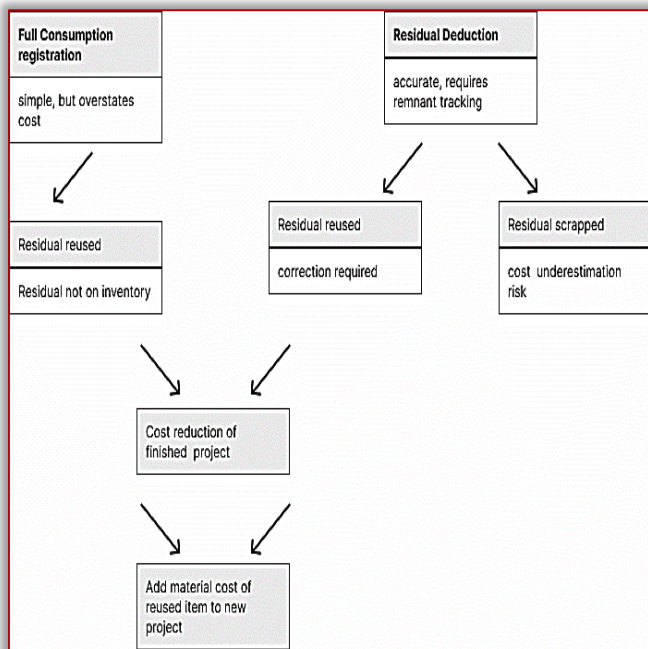


Figure 1.: Decision tree

This decision tree highlights the trade-off between accuracy and administrative burden. Managing residual material is not only a technological and accounting problem but also a resource management issue. The additional tasks of identification, handling, and project recalculation cause significant burden on the company.

In this case each remnant must be measured, tagged, and recorded during the identification process. This requires skilled labour or automated systems such as scanners and RFID tagging. These add time and cost per production batch. Manual classification increases the risk of error, while automation requires capital expenditure and ongoing maintenance.

The handling and inventorying of residual sheets and bar segments also often need separate storage racks, labelling systems, and retrieval processes. Forklift or manual handling introduces non-value-adding logistics movements, while irregularly shaped remnants complicate warehouse processes and layout. The opportunity cost of floor space allocated to remnants can be significant, especially in high-throughput factories.

When remnants are later reused or scrapped – e.g. months later of the original production, the initial post-calculation must be corrected. This requires back-office staff to revisit closed cost records, modify ERP entries, and sometimes update financial reports. Such retrospective changes increase administration, reduce transparency, and can be against the

accounting and auditing principles of the company.

The above disadvantages create an additional layer of hidden cost that is rarely captured by the controlling department, in standard production metrics. Companies must weigh the potential material savings against these organizational burdens. In many cases, the overhead of tracking and recalculating might exceed the value of the material recovered, leading some firms to favour simplified accounting approaches even if they sacrifice precision.

POSSIBLE TECHNOLOGICAL SOLUTIONS

Technologies like digital twins, IoT-based material tracking, and AI-driven predictive models could reduce uncertainty by estimating the probability of remnant reuse based on production history and demand forecasts. In practice, a digital twin of the shop floor can dynamically represent the state of each raw material sheet or bar, holding the dimension values of the product and predicting future usability.

RFID or barcode tagged remnants ensure traceability across storage and assembly/manufacturing. Machine learning models can learn from historical demand patterns to forecast the likelihood of reuse within given planning horizons. This allows integration with advanced production planning and control systems, where remnants are treated as probabilistic inventory rather than binary usable/non-usable stock. Several studies deal with integration and technological development of cutting stations (e.g.: [9]). Application of Industry 4.0 principles also contribute to efficiency increase [10].

We can use automated classification of remnants by advanced nesting algorithms to increase the probability of utilization, especially when the IT system is connected with real-time ERP/MES systems. The use case is very rare, but blockchain-based traceability systems can establish integrity of remnant data across supply chain partners. However the application of these systems need significant investment, interoperability standards, and workforce training.

Simple reporting techniques like defining minimal dimensions of residual material based on historical data can be an initial step to solve the dilemma of scrapping/inventorying a residual material. Analysing and finding relation between obsolete BOM structure of historical orders and remnants used during the

production of these orders requires developed data mining techniques and proper collection of material data. Catching dimension data of residual quantity and flagging dimension inadequacy of obsolete inventory can contribute to providing sufficient information for this decision problem.

CONCLUSION

Accurate material allocation in laser cutting, shearing, and bar stock machining remains a complex challenge shaped by the uncertain usability of residual materials. While existing approaches simplify the problem either by overestimating or underestimating costs, neither provides a definitive solution. The integration of advanced tracking technologies and predictive models represents a promising direction but must be balanced against economic realities. Ultimately, the problem is not only technological but also managerial, requiring a systemic approach to cost allocation, sustainability, and production planning.

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