International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 06 Issue:12 | Dec-2022 SJIF Rating: 7.185 ISSN: 2582-3930

Optimizing Facility Layout & Material Flow Logistics for Productivity Enhancement: A Systematic Engineering Approach

Vandana Tiwari

Lecturer, Mechanical Engineering Department, Govt. Polytechnic College, Sanawad Mail id-mrsvandanatiwari@gmail.com

Abstract

Shorter material routes create an opportunity for productivity improvement, but output increases only when released time benefits a capacity constraint. This paper develops a deterministic bottleneck model for a xyz small-scale manufacturing unit using a fully disclosed synthetic dataset. Existing and improved layout scenarios share seven process areas, six workers, and an eight-hour paid shift. At a reference workload of 240 units, the associated route-and-time model releases 41.07 handling labour minutes per shift. The productivity model separately assumes that 35 min of bottleneck starvation are eliminated while intrinsic processing speed, staffing, and yield remain constant. Gross output consequently increases from 240 to 266 whole units per shift, a 10.83% gain. At a fixed 98% yield, expected acceptable output increases from 235.20 to 260.68 units, and paid labour productivity rises from 4.90 to 5.43 acceptable units per labour-hour. Sensitivity analysis shows that no output gain occurs when the recovered time fails to reach the bottleneck; demand and downstream capacity also cap the benefit. Higher output partially offsets the reduction in total daily transport. The study's contribution is an explicit, auditable connection between layout-related handling savings and conditional throughput improvement. The findings are illustrative analytical results, not measured production achievements.

Keywords: labour productivity; material flow; workplace layout; bottleneck; small-scale manufacturing; capacity analysis

1 Introduction

Productivity improvement requires a manufacturing unit to produce more acceptable output from a defined input of labour, equipment, time, or capital. Workplace layout can contribute by reducing the work needed to deliver material between operations and by improving the timing of that delivery. However, a reduction in travel is not equivalent to an increase in finished output. A process can become easier to supply while remaining constrained by a machine, inspection activity, unavailable component, or limited demand. The relationship between layout and productivity must therefore be explained through the operating constraint that determines production.

This issue is particularly relevant to small-scale manufacturing, where equipment, workers, and transport tasks may be closely interdependent. A worker can alternate between processing and handling, and a late transfer can interrupt a machine that otherwise has adequate technical capacity. Rearranging work areas may create additional usable time without changing the machine's intrinsic cycle. The resulting benefit depends on whether that time becomes available where and when the production system needs it. A layout project should consequently distinguish released handling labour from recovered productive machine time.

Studies using simulation illustrate the relevance of multiple performance measures. Jayachitra and Prasad (2010) compare layouts through operational outcomes, and Dombrowski and Ernst (2013) use scenarios to evaluate layout alternatives under changing requirements. Such approaches are useful because the same arrangement can perform differently under different workloads. For a compact analytical study, the corresponding requirement is to state the capacity limits and vary the connection between handling improvement and the bottleneck rather than assume that the two change proportionately.

The bottleneck supplies a practical basis for this connection. Its productive minutes determine an output ceiling when upstream supply, downstream processing, and demand are sufficient. If shorter delivery removes starvation, the bottleneck can produce for a greater share of the available shift. If the saved handling time occurs during periods in

which the bottleneck is already busy, output may remain unchanged. Similarly, increasing bottleneck capacity beyond a downstream constraint shifts the restriction rather than creating unlimited additional throughput.

A second issue concerns the productivity denominator. More output can result from additional labour or overtime rather than improved performance with unchanged resources. Paid labour-hours must therefore be held constant or explicitly recalculated. Quality also matters: gross output and acceptable output are different quantities. A layout that raises production but causes additional damage or defects may generate a smaller improvement in saleable output. The present analysis retains both the paid-hour denominator and an explicit yield term to keep the productivity statement interpretable.

The study evaluates a small-scale manufacturing process with seven work areas, six workers, and a common shift structure. The handling model identifies time released by shorter routes and reduced waiting at a fixed reference workload. The productivity model then relates this release to a specified reduction in bottleneck starvation while holding intrinsic processing speed and staffing constant. Demand and upstream and downstream capacities provide further limits. The analysis also recalculates material handling at the higher output, including the incomplete final batch, so that improved productivity is not paired with transport totals from a different workload.

The objective is to establish the conditions under which improved material flow translates into higher acceptable output per paid labour-hour. The paper examines the magnitude of the gain, its sensitivity to recovery at the bottleneck, and the effects of demand, capacity, and yield. Its contribution is the explicit reconciliation of spatial efficiency, productive time, and output-adjusted handling requirements. The resulting framework explains why a substantial handling improvement can yield a more modest productivity gain and why shorter routes can remain beneficial even when output is capped.

2 Literature and Productivity Mechanism

Facility layout determines spatial relationships, while realized productivity depends on the operation of the production system. Pérez-Gosende et al. (2021) review layout planning in an operations-management context. Anjos and Vieira (2017) and Hosseini-Nasab et al. (2018) establish that layout problems differ in their representations and constraints. Anjos and Vieira (2021) further show why a mathematical layout claim depends on its defined structural model.

Operational evaluation is therefore central to interpreting a rearrangement. Jayachitra and Prasad (2010) compare layouts using simulation-based performance measures. De Carlo et al. (2013) examine layout alternatives alongside a broader lean redesign of a low-capacity line. These studies support consideration of flow and output together, but they do not justify assigning a universal productivity percentage to route shortening.

The analytical mechanism has three steps. First, a layout reduces handling labour for a common quantity of material. Second, some of that released time improves the timely availability of work at the bottleneck. Third, the bottleneck produces additional units only if demand and other resources can absorb them. Skipping the second or third step makes an output claim unsupported.

The study distinguishes handling labour, bottleneck productive minutes, and paid labour-hours. They have different physical meanings and cannot be exchanged one for one without an explicit assumption. In particular, a handler's saved minute does not automatically become a machine's productive minute. Concurrent tasks, scheduling, and starvation timing determine the connection.

The research questions are the size of the conditional productivity gain, the fraction of handling savings that must benefit the bottleneck, and the influence of demand, quality, and downstream capacity. An additional question concerns whether total daily movement remains lower once production volume increases. All questions are addressed using disclosed deterministic scenarios rather than fabricated operating records.

Movement and capacity must also be linked through a usable route structure. Pourvaziri et al. (2021) integrate aisles into layout design, and Kikolski and Ko (2018) examine workstation arrangement methods. Their relevance to productivity appraisal is that proximity alone cannot establish timely delivery. The path through which a handler reaches a workstation forms part of the production connection being evaluated.

The present study therefore evaluates handling once at equal output and again at the higher output implied by the capacity model. This workload reconciliation distinguishes technical transport efficiency from the total daily logistics requirement and avoids crediting the productivity scenario with the movement total of the lower-volume scenario.

3 System Description and Common Dataset

The synthetic production system processes one bracket family through storage, cutting, drilling, deburring, assembly, inspection, and finished staging. It employs six workers for an eight-hour paid shift. Scheduled breaks and allowances remove 60 min, leaving a 420-min net operating window. Staffing and paid hours remain unchanged after layout improvement.

The reference handling comparison transports 240 units in twelve batches of twenty. Existing and improved cumulative loaded routes are 114 and 50 m per batch. With loaded speed 0.80 m/s, empty speed 1.20 m/s, 40 s of transfer work on each link, and waiting allowances of 20 and 8 s, handling labour declines from 119.50 to 78.43 min per reference shift.

Table 1. Synthetic capacity assumptions

Parameter	Existing	Improved
Paid labour input	6 × 8 = 48 h	48 h
Net operating window	420 min	420 min
Other bottleneck downtime	30 min	30 min
Bottleneck starvation	70 min	35 min
Intrinsic bottleneck cycle	4/3 min per unit	4/3 min per unit
Upstream gross capacity	280 units	280 units
Downstream gross capacity	275 units	275 units
Demand ceiling	300 gross units	300 gross units
Acceptable yield	98%	98%

Study design and data provenance. This deterministic numerical study uses synthetic route, labour, and capacity data. The improved-flow scenario reduces bottleneck starvation by 35 min while preserving staffing and processing speed. The conversion and sensitivity analyses evaluate this operational condition explicitly; the results describe the modelled system rather than measured factory performance.

4 Model Formulation and Calculation Boundaries

Let T be the net operating window, D other bottleneck downtime, S starvation, and c the intrinsic bottleneck cycle. Available productive time is B = T − D − S. Continuous bottleneck capacity is Cb = B/c. Gross daily output Q is the integer floor of the minimum of Cb, upstream capacity Cu, downstream capacity Cd, and demand ceiling Qd.

Expected acceptable output is G = yQ, where y is acceptable yield. Paid labour productivity is PL = G/(nHp), with n workers and Hp paid hours per worker. Net-time productivity is a separate measure, G/[n(T/60)], and is not substituted for the paid-hour denominator. Fractional acceptable output represents an expected average, not a fractional completed item in a particular shift.

The baseline productive time is 420 − 30 − 70 = 320 min. At 4/3 min per unit, capacity is 240 units. The improved productive time is 420 − 30 − 35 = 355 min, giving continuous capacity of 266.25 units. Since upstream capacity, downstream capacity, and demand exceed this figure, feasible whole-unit output is 266.

Table 2. Derived baseline and improved performance

Measure	Existing	Improved
Productive bottleneck time	320 min	355 min
Gross whole-unit output	240	266
Expected acceptable output	235.20	260.68
Paid labour productivity	4.900 units/h	5.431 units/h
Net-time labour productivity	5.600 units/h	6.207 units/h
Productive share of net window	76.19%	84.52%

The productive share is not overall equipment effectiveness. Performance losses and quality are not combined into a standard equipment-effectiveness calculation here. Restricting the label to productive time avoids overstating what the available variables measure.

5 Productivity Results and Conversion Of Time

The model produces 26 additional gross units per shift, equivalent to 10.83% above baseline. With yield fixed at 98%, the expected acceptable increment is 25.48 units. Paid labour input remains 48 h, so labour productivity increases by the same percentage, from 4.90 to 5.43 acceptable units per paid labour-hour. No additional labour, faster processing, or improved quality is embedded in that result.

The handling comparison releases 41.07 min at the reference output. Recovering 35 min of bottleneck starvation corresponds to a conversion factor of 35/41.07 = 0.8523. This factor summarizes a scheduling assumption: approximately 85.23% of the reference handling saving becomes additional productive bottleneck time. It is not a measured transfer efficiency.

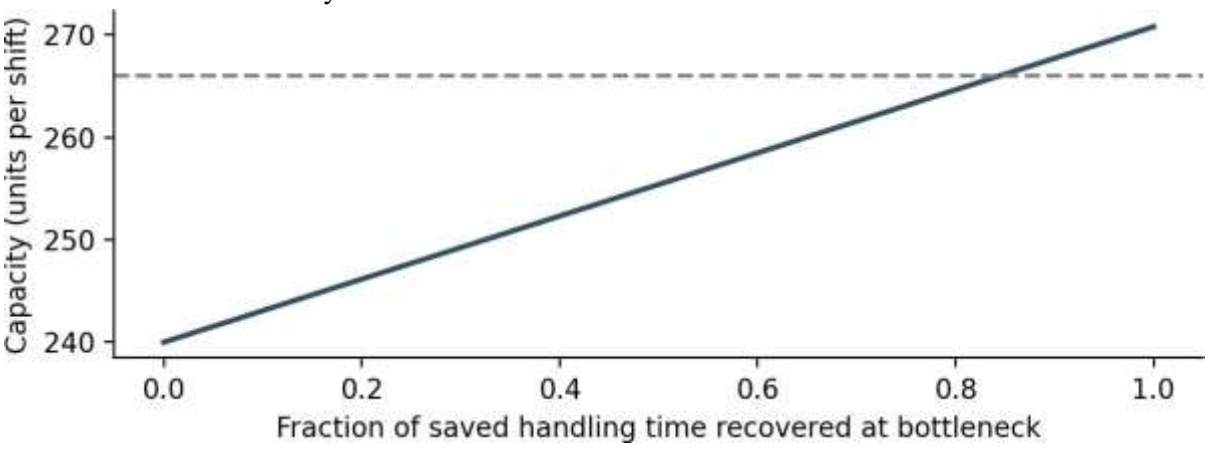


Figure 1. Continuous gross capacity as the conversion factor varies from zero to one, with the other base assumptions fixed. Whole-unit output is obtained by rounding down.

A conversion factor of zero leaves output at 240 units even though travel becomes shorter. At 0.50, continuous capacity becomes 255.40 units, permitting 255 whole units. At one, it reaches 270.80 units, permitting 270 whole units. The base assumption lies between these bounds and remains below the downstream limit of 275.

This result explains why the productivity increase is much smaller than either the route reduction or the handling-time reduction. The route change affects only part of labour time, and only part of that saving affects the capacity constraint. Productivity therefore follows a conditional operational mechanism rather than a proportional distance rule.

6 Movement and Labor at Higher Output

The earlier handling and distance comparisons use equal output to isolate layout intensity. Actual daily totals in the productivity scenario must instead reflect the higher output. For 266 units, thirteen full twenty-unit batches and one six-unit batch require fourteen dispatches on each route. Assuming a full route and the same fixed handling work for the partial batch, improved handling labour becomes 14 × 392.17/60 = 91.51 min per shift.

Improved loaded carrier travel is 14 × 50 = 700 m rather than the 600 m calculated for 240 units. With equal returns and the same 240 m of ancillary walking, defined worker-distance becomes 1,640 m. These output-adjusted totals remain below baseline, but their reductions are smaller than the equal-workload reductions.

Table 3. Equal-output and higher-output comparisons

Indicator	Existing 240	Improved 240	Improved 266
Dispatch batches	12	12	14
Handling labour min	119.50	78.43	91.51
Loaded carrier-distance m	1,368	600	700
Defined worker-distance m	3,456	1,440	1,640
Handling seconds per unit	29.88	19.61	20.64

At the higher output, total handling labour is still 23.43% below baseline and worker-distance is 52.55% lower. The per-unit handling requirement increases slightly relative to the improved 240-unit scenario because the final batch is only partially filled. This batch-boundary effect is lost if all handling is approximated as perfectly proportional to output.

The model's reference conversion factor is an appraisal relationship, not a steady-state conservation identity between net handling labour savings and machine minutes. After output increases, extra transport consumes some released labour while improved delivery timing can still reduce starvation. A dynamic model would be needed to establish that the assumed 35-min recovery remains operationally attainable. The present calculation confirms task-time capacity for the defined handler, but does not prove an executable schedule.

7 Demand Capacity and Quality Sensitivity

The bottleneck calculation sets a conditional upper bound on output. A demand ceiling of 250 units limits improved output to 250 even when physical capacity is 266.25. A downstream capacity of 250 produces the same cap. In either scenario, the gross improvement is 4.17% rather than 10.83%. With a demand ceiling of 240, output does not increase at all.

Table 4. Synthetic sensitivity results with baseline output of 240

Improved scenario	Gross units	Expected good units	Paid units/h
Base recovery of 35 min	266	260.68	5.431
No bottleneck recovery	240	235.20	4.900
Recovery factor 0.50	255	249.90	5.206
Recovery factor 1.00	270	264.60	5.513
Demand or downstream cap 250	250	245.00	5.104

Yield falls to 95%	266	252.70	5.265

Quality deterioration can consume some of the output gain. At 95% yield, expected acceptable output becomes 252.70 units, still above the baseline 235.20 but below the base improved scenario. The break-even improved yield for acceptable output is 235.20/266 = 88.42%. This is a mathematical threshold, not an acceptable quality target.

A working-capital implication can also be illustrated, provided its assumptions remain explicit. If average work in process is assigned values of 60 and 45 units, a stable-flow relation gives average lead time as WIP divided by gross throughput rate. Using the 420-min net window produces 105.00 min before improvement and 71.05 min after improvement. The lower WIP is a separate scenario input; it is not predicted by shorter routes.

This distinction prevents a chain of assumed improvements from masquerading as independent evidence. The capacity calculation supports the output result only under the starvation assumption. The lead-time result additionally requires stable average flow and the specified WIP levels. No observed distribution, confidence interval, or statistical test is implied by these calculations.

8 Discussion and Managerial Interpretation

The productivity mechanism is the alignment of material availability with the limiting production resource. Layout improvement can shorten delivery and reduce avoidable access delay, but the operational value depends on when those savings occur. Minutes saved during a bottleneck's already productive period may not increase output. Minutes that remove starvation can have a direct capacity effect.

The base model illustrates this distinction by holding intrinsic processing time constant. The bottleneck does not become faster; it spends more of the net window producing. The resulting 10.83% gain is therefore a utilization effect under an assumed starvation reduction. It should not be described as a technological improvement in machine speed or as proof of improved worker effort.

The fixed staffing denominator also makes the productivity claim clear. Acceptable output per paid labour-hour rises because output increases with unchanged paid hours. If additional staffing or overtime were required to sustain fourteen dispatch batches, the denominator would change. Conversely, released handling time does not justify a claim of reduced headcount without a complete assignment and coverage analysis.

A useful implication concerns investment appraisal. The 25.48 additional expected acceptable units per shift can be multiplied by a documented contribution margin and the number of attainable operating days to estimate gross contribution potential. No monetary saving is calculated here because neither contribution margin nor relocation cost has been supplied. Counting released labour as a cash saving and simultaneously counting the resulting extra output could double count the same benefit.

The output-adjusted movement calculation is equally important. Reporting the improved 600 m carrier-distance alongside 266 units would mix two different workloads. Correcting the dispatch count raises improved travel to 700 m and handling labour to 91.51 min. The layout remains beneficial, but the daily saving is smaller than its fixed-output technical comparison suggests.

The case also shows why short routes alone are an incomplete objective. If downstream inspection becomes constrained, additional upstream release may raise queues rather than completed output. If demand is fixed, the benefit may instead appear as spare capacity, responsiveness, or lower transport effort. Those outcomes can be valuable, but they are different from the productivity gain calculated here and require their own evidence.

9 Limitations and Conclusion

This is a synthetic analytical study, not an implemented manufacturing case. The main limitation is the assumed connection between reduced handling and reduced starvation. The conversion factor is exposed precisely because it cannot be inferred from route distance alone. The model does not reproduce dispatch timing, competing jobs, buffer blocking, or worker task precedence, and therefore does not validate a feasible detailed schedule.

The capacity constraints are fixed gross-unit ceilings for a single product. A changing product mix, sequence-

dependent setup, equipment failure, or variable yield could alter the bottleneck. The partial-batch calculation improves the handling estimate but still assigns identical load-and-unload time to full and partial containers. This is a conservative simplification of fixed dispatch work rather than a measured service-time function.

Under the stated assumptions, reducing bottleneck starvation from 70 to 35 min raises whole-unit output from 240 to 266 per shift. Expected acceptable output increases from 235.20 to 260.68 units, while paid labour productivity increases from 4.90 to 5.43 units per labour-hour. The gain disappears when no handling saving benefits the bottleneck and is constrained by demand and downstream capacity.

The principal conclusion is that layout improvement creates productivity potential, while flow synchronization determines whether that potential is realized. A defensible productivity model must disclose the time-conversion assumption, retain quality and labour denominators, and recalculate logistics at the resulting output. This approach produces a narrower but more interpretable claim than assigning output gains directly from a distance-reduction percentage.

Data availability. The model inputs and calculation rules are reported in the methods and tables. All results can be reproduced from the disclosed dataset.

References

Anjos, M. F., & Vieira, M. V. C. (2017). Mathematical optimization approaches for facility layout problems: The state-of-the-art and future research directions. *European Journal of Operational Research, 261*(1), 1–16. https://doi.org/10.1016/j.ejor.2017.01.049

Anjos, M. F., & Vieira, M. V. C. (2021). Mathematical optimization approach for facility layout on several rows. *Optimization Letters, 15*, 9–23. https://doi.org/10.1007/s11590-020-01621-z

De Carlo, F., Arleo, M. A., Borgia, O., & Tucci, M. (2013). Layout design for a low capacity manufacturing line: A case study. *International Journal of Engineering Business Management, 5*, 1–10. https://doi.org/10.5772/56883

Dombrowski, U., & Ernst, S. (2013). Scenario-based simulation approach for layout planning. *Procedia CIRP, 12*, 354–359. https://doi.org/10.1016/j.procir.2013.09.061

Hosseini-Nasab, H., Fereidouni, S., Fatemi Ghomi, S. M. T., & Fakhrzad, M. B. (2018). Classification of facility layout problems: A review study. *The International Journal of Advanced Manufacturing Technology, 94*, 957–977. https://doi.org/10.1007/s00170-017-0895-8

Jayachitra, R., & Prasad, P. S. S. (2010). Design and selection of facility layout using simulation and design of experiments. *Indian Journal of Science and Technology, 3*(4), 437–446. https://doi.org/10.17485/ijst/2010/v3i4.20

Kikolski, M., & Ko, C.-H. (2018). Facility layout design—Review of current research directions. *Engineering Management in Production and Services, 10*(3), 70–79. https://doi.org/10.2478/emj-2018-0018

Pérez-Gosende, P., Mula, J., & Díaz-Madroñero, M. (2021). Facility layout planning. An extended literature review. *International Journal of Production Research, 59*(12), 3777–3816. https://doi.org/10.1080/00207543.2021.1897176

Pourvaziri, H., Pierreval, H., & Marian, H. (2021). Integrating facility layout design and aisle structure in manufacturing systems: Formulation and exact solution. *European Journal of Operational Research, 290*(2), 499–513. https://doi.org/10.1016/j.ejor.2020.08.012