International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 05 Issue:07 | Jul-2021 SJIF Rating: 6.714 ISSN: 2582-3930

Workplace Layout Optimization: A Systematic Approach to Minimize Operator Fatigue & Material Handling Bottlenecks

Vandana Tiwari

Lecturer, Mechanical Engineering Department, Govt. Polytechnic College, Sanawad

Mail id- mrsvandanatiwari@gmail.com

Abstract

Worker movement and material travel are often combined into one distance indicator, although they describe different physical flows. This paper develops a dual-accounting model for a xyz small manufacturing unit with seven process areas. A synthetic route dataset compares existing and improved arrangements at a common workload of 240 units in twelve batches. Loaded material travel is evaluated independently from empty return walking and ancillary supply movement. The cumulative loaded route decreases from 114 to 50 m per batch, reducing loaded carrier travel from 1,368 to 600 m per reference shift, or 56.14%. Worker travel, including equal-distance returns and explicitly assumed ancillary walks, decreases from 3,456 to 1,440 m, or 58.33%. Part-distance falls from 27,360 to 12,000 unit-metres while the number of material transfers remains unchanged. A geometry-only comparison separates relocation benefits from point-of-use supply assumptions. Sensitivity tests examine unequal route frequencies, return policies, and additional detours. The contribution is a reproducible distinction between route length, carrier-distance, part-distance, and worker-distance. The results demonstrate conditional movement reduction without claiming measured ergonomic improvements, collision reduction, or an implemented factory redesign.

Keywords: worker movement; material travel distance; workplace layout; from-to analysis; point-of-use storage; route accounting

1 Introduction

Workplace layout establishes the paths through which materials and people connect individual production operations. When related work areas are dispersed, each batch can accumulate unnecessary travel even though its technological sequence remains unchanged. The corresponding movement is not limited to the product. A handler may accompany the loaded container, return empty, retrieve a tool, and collect consumables from another location. These movements consume space and labour and can interfere with timely delivery to subsequent operations. Understanding them requires more than a single line connecting the first and last workstation.

The central measurement problem is that material travel and worker movement describe different physical entities. A carrier transporting twenty components over ten metres travels ten carrier- metres, whereas the components collectively travel two hundred unit-metres. If the handler returns to the starting point, the worker covers twenty metres before beginning the next task. Each figure is correct within its own boundary. Using the terms interchangeably can nevertheless make two layout evaluations appear inconsistent or can lead to double counting when overlapping measures are added together.

A small manufacturing unit provides a useful setting for examining this distinction. Sequential processing can coexist with distributed storage, shared tools, and manually coordinated replenishment. A process-oriented layout may be convenient for equipment grouping while creating long connections between successive operations of a particular product family. Conversely, placing operations closer can simplify material movement but leave supply retrieval unchanged. A complete movement analysis must therefore distinguish changes in the main production route from changes in supporting storage and replenishment arrangements.

Facility-layout studies offer several ways to represent spatial relationships and flow intensity. Kikolski and Ko

(2018) review workstation-layout methods, while Hosseini-Nasab et al. (2018) classify layout problems by their principal characteristics. The common analytical requirement is to identify which relationships the objective function represents. A frequency-weighted route measure is more informative than an unweighted sum of station separations when some transfers occur more often than others. It also requires travel distance along accessible paths, because the direct separation between two locations may cut across equipment or an unavailable aisle.

The relationship between worker flow and material flow has received explicit attention in recent research. A shorter route may reduce walking, but it does not by itself demonstrate fewer lifts, lower push force, or reduced interaction with vehicles. The physical distance outcome must be reported accurately before broader ergonomic or safety conclusions can be considered.

The present paper addresses movement through four complementary measures: cumulative route length per batch, loaded carrier-distance per shift, aggregate unit-distance, and worker-distance including empty and ancillary movement. The analysis uses a common seven-area process and a reference workload of twelve twenty-unit batches. Existing and improved routes retain the same sequence and number of transfers. A separate point-of-use supply scenario changes ancillary trip length while retaining its frequency. This structure makes the contribution of process relocation distinguishable from that of supply placement.

The principal objective is to quantify how layout improvement changes material and worker travel without mixing measurement units or operating workloads. The analysis asks how much loaded distance is removed, how empty returns and ancillary walking alter the worker result, and whether the conclusion persists when frequencies, return policies, and detours change. These questions are particularly relevant when an improvement proposal is expressed as a single percentage but several movement mechanisms are involved.

The paper contributes a transparent accounting framework and a controlled comparison of spatial changes. Its emphasis is on interpreting the resulting quantities: distance reduction does not necessarily mean fewer movement events, and lower loaded travel does not capture every worker trip. By retaining the unchanged transfer count and presenting the components separately, the analysis explains both the potential and the limits of the improved arrangement. The subsequent sections develop the literature basis, define the movement boundaries, derive the calculations, and examine the sensitivity and operational meaning of the results.

2 Literature and Research Focus

A layout model must specify what moves, how often it moves, and which paths are accessible. Hosseini-Nasab et al. (2018) distinguish facility-layout problems through their constraints and characteristics. Anjos and Vieira (2017) examine optimization formulations These contributions provide a basis for distinguishing a route-network comparison from a solved physical placement problem.

For the present study, the relevant implication is that the material-handling system forms part of the layout problem definition. A distance metric without an explicit handling policy is incomplete: a dedicated return trip and a chained delivery tour produce different worker exposure even when the loaded material route is identical.

Earlier operational studies offer complementary evaluation perspectives. Jayachitra and Prasad (2010) include travel distance among simulation performance measures. De Carlo et al. (2013) compare redesign alternatives for a low-capacity line. The present paper does not reproduce their empirical contexts. It develops a small, fully disclosed calculation that distinguishes carrier movements from the total distance travelled by all units within a batch.

The analytical contribution is a four-part measurement framework: one-way route length, loaded carrier-distance, unit-distance, and worker-distance including empty movement. It addresses a reporting ambiguity rather than claiming that distance minimization itself is new. A further contribution is a controlled decomposition of the total worker-distance improvement into route geometry and ancillary supply placement.

The primary questions concern the reduction in material travel at fixed output, the additional movement captured when workers are tracked, and whether the apparent advantage persists under alternative return and flow assumptions. The answers are deterministic scenario results. No inference about injury, fatigue, or statistically significant differences follows from the synthetic distances.

In the present model, the path length is therefore the relevant input, and additional detours are evaluated explicitly. This preserves the distinction between a short station separation and a short accessible route without introducing unverified geometric coordinates.

These contributions frame the scope of this study: the main comparison retains a fixed product route, while sensitivity cases vary flow frequency and return policy. The alternative cases test the measurement framework under changed logistics conditions; they do not treat a fixed-flow result as universally transferable. The research gap addressed here is the interpretation of overlapping distance indicators within an explicitly bounded handling system.

3 Manufacturing Scenario and Movement Definitions

The xyz unit produces one bracket family through raw-material storage, cutting, drilling, deburring, assembly, inspection, and finished staging. These areas are coded R, C, D, B, A, I, and F. The production route is fixed, with no rework or branching in the reference scenario. Each of twelve batches contains twenty units and traverses each of six links once.

A loaded carrier-distance records the distance travelled by a batch carrier regardless of how many parts it carries. Unit-distance records the distance travelled by every part and is expressed in unit-metres. Worker-distance includes walking during loaded movement, empty returns, and ancillary supply tasks. These measures overlap physically but answer different questions; they are not added together.

Table 1. Measurement boundaries and synthetic inputs

Measure or assumption	**Definition or value**
Reference production	240 units; 12 batches of 20
Loaded route sum	Existing 114 m; improved 50 m per batch
Return rule	One equal-length empty return per loaded transfer
Ancillary supply tasks	24 round trips per shift in both scenarios
Ancillary trip length	Existing 30 m; improved 10 m round trip
Workers represented	Movement assigned to the handling function
Excluded movement	Personal breaks, commuting, and unmodelled tasks

Ancillary trips represent supply retrieval rather than additional product transfers. Their frequency remains unchanged while their round-trip length falls under point-of-use supply placement. Study design and data provenance. The route lengths, flow counts, and trip rules form a synthetic numerical dataset. Worker-distance covers the defined handling function, including loaded, return, and ancillary movement; it does not represent all walking by the production team.

4 Route Representation and Layout Logic

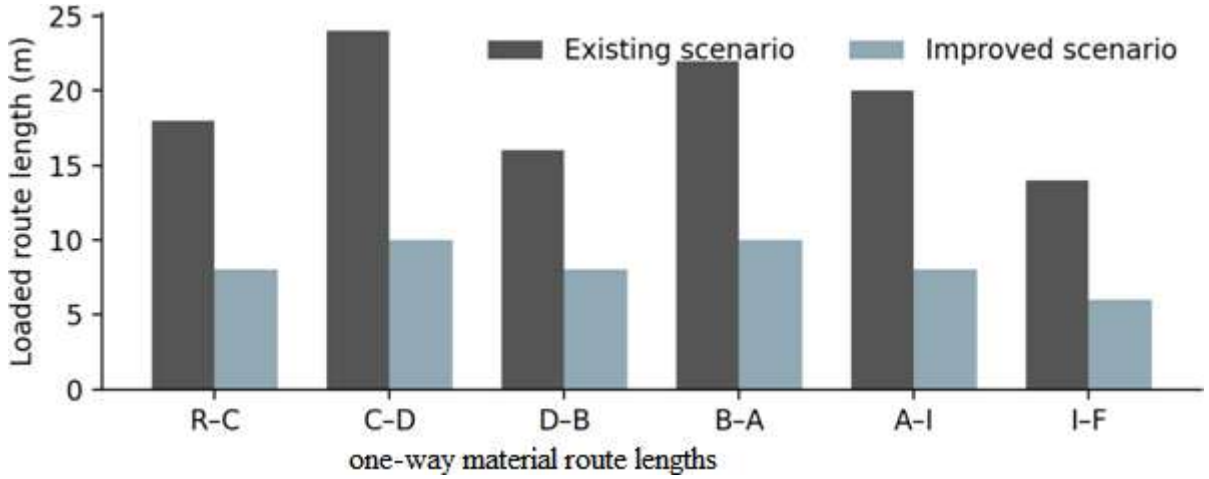


Figure 1. Synthetic one-way material route lengths before and after the layout change. R = raw storage; C = cutting; D = drilling; B = deburring; A = assembly; I = inspection; F = finished staging.

The existing scenario represents dispersed sequential work areas. The improved scenario shortens the connections while maintaining process order. The figure is a route-length comparison, not a scaled floor plan. It avoids implying that unspecified machines, doors, or aisle widths have been physically verified.

A from-to representation records only the six forward links in the base model. Their frequencies are all twelve loaded trips per shift. Every other product-flow entry is zero by assumption. Empty return walking is recorded separately rather than entered as reverse product flow, because no batch is transported on the return leg.

The planning logic favours adjacency of successive operations, clear access to transfer points, and shorter supply retrieval. However, proximity alone is not a feasibility test. An arrangement must still accommodate equipment envelopes, access for maintenance, required separation, and usable paths. Those geometric constraints are outside the supplied information and are not replaced by an unsupported safety claim.

Distance is measured along the assumed accessible route. Straight-line distance between station centres is not substituted for travel distance. This choice matters because two nearby workstations may still require a long route around equipment or barriers. Additional detours are examined explicitly in the sensitivity analysis.

5 Mathematical Model and Baseline Calculation

For route i, let f_i be loaded trips per reference shift, d_{ik} the accessible one-way length in layout k, and b_i the units per loaded trip. Loaded carrier-distance is $M_k = \Sigma f_i d_{ik}$. Unit-distance is $U_k = \Sigma f_i b_i d_{ik}$.

With a return-distance ratio r_{ik} and ancillary movement A_k, worker-distance is $W_k = \Sigma f_i d_{ik}(1 + r_{ik}) + A_k$.

The base case sets $f_i = 12$, $b_i = 20$, and $r_{ik} = 1$ for all links. Ancillary movement is $24 \times 30 = 720$ m in the existing scenario and $24 \times 10 = 240$ m in the improved scenario. A percentage reduction always uses the corresponding baseline measure as denominator.

Table 2. Synthetic from-to movement calculation at fixed output

Link	Trips	Old loaded m	New loaded m	Saved m
R–C	12	216	96	120
C–D	12	288	120	168
D–B	12	192	96	96
B–A	12	264	120	144

A–I	12	240	96	144
I–F	12	168	72	96
Total	72	1,368	600	768

The six-link cumulative route falls by 64 m per batch. Multiplying this change by twelve batches gives 768 m less loaded carrier travel. Multiplying again by twenty units per batch gives 15,360 fewer unit-metres. These are two descriptions of the same transported workload, not independent savings to be summed.

The number of loaded transfers remains 72. Each transfer also has an empty return, giving 144 main-route walking legs. The model therefore reduces the lengths of movements without reducing their count. This distinction prevents the phrase "movement reduction" from being interpreted as fewer lifts or handling events.

6 Results and Decomposition of Worker Travel

Table 3. Movement outcomes for the synthetic reference shift

Indicator	**Existing**	**Improved**	**Reduction**
Loaded carrier-distance	1,368 m	600 m	56.14%
Empty return walking	1,368 m	600 m	56.14%
Ancillary walking	720 m	240 m	66.67%
Total defined worker-distance	3,456 m	1,440 m	58.33%
Unit-distance	27,360 unit-m	12,000 unit-m	56.14%
Loaded transfers	72	72	0.00%

The worker-distance reduction is 2,016 m per reference shift. Main-route shortening accounts for 1,536 m because each loaded distance reduction also removes an equal-distance return. Shorter ancillary trips account for the remaining 480 m. Their shares of the total worker-distance saving are 76.19% and 23.81%, respectively.

A geometry-only alternative retains the original 720 m of ancillary walking. Its worker-distance is 1,920 m, a 44.44% reduction from the baseline. Adding point-of-use supply placement raises the total reduction to 58.33%. The distinction is important because moving process stations does not automatically move consumables or tools closer to their point of use.

At the common production volume, allocated worker travel falls from 14.40 to 6.00 m per unit. Loaded carrier-distance falls from 5.70 to 2.50 m per unit, while each individual unit physically follows 114 m in the existing route and 50 m in the improved route. The apparently different unit values reflect batching: one carrier trip transports twenty parts.

The largest single loaded-route saving occurs on cutting to drilling, which contributes 168 m per shift. Deburring to assembly and assembly to inspection each contribute 144 m. Together these three links account for 59.38% of the loaded-distance reduction. Their prominence follows from the chosen equal flow frequencies and should not be interpreted as a universal ranking of manufacturing operations.

7 Sensitivity to Flow and Return Policies

Unequal flows change the weighting of individual links. An alternative frequency vector of 18, 12, 12, 12, 12, and 18 trips produces 1,560 m of existing loaded travel and 684 m of improved travel, a 56.15% reduction. This is a separate logistics scenario with more frequent endpoint movements, not the unchanged twelve-batch base case. It

illustrates the method without confusing extra trips with extra finished output.

Table 4. Alternative assumptions and corresponding travel outcomes

Scenario	Old distance m	New distance m	Reduction
Base loaded carrier travel	1,368	600	56.14%
Unequal loaded trip frequencies	1,560	684	56.15%
Improved main routes 20% longer	1,368	720	47.37%
Worker travel with 50% returns in both	2,772	1,140	58.87%
Worker travel with no supply relocation	3,456	1,920	44.44%

The return-ratio sensitivity sets r = 0.5 in both scenarios. It represents partial chaining of tasks, not a new measured worker pattern. Since main-route distance has a lower weight relative to ancillary walking, the percentage worker-distance reduction changes slightly. A more efficient return policy in only one scenario would represent an additional intervention and should be reported as such.

If every improved route includes an equal additional detour δ, the improved cumulative loaded route becomes 50 + 6δ. Its material-distance advantage disappears when δ = 10.67 m per link. For total worker travel, the retained ancillary saving allows the improved cumulative route to rise to 134 m before reaching the baseline 3,456 m. This corresponds to δ = 14 m per link.

The different thresholds demonstrate why one metric cannot stand in for another. Material travel may lose its advantage while worker travel still benefits from shorter supply retrieval. No probability is attached to these thresholds. They are exact consequences of the stated model, and their value is in identifying what physical features could change the result.

8 Discussion of Flow and Human Movement

The results support a spatial explanation of the handling-time findings without equating the two outcomes. Distance accounts for the travel component of labour, while loading, unloading, and waiting contribute time without necessarily contributing metres. The companion handling-time analysis therefore reports a smaller percentage reduction than the present material-distance result. Both statements can be correct under the same route assumptions.

The more consequential distinction is between transporting material and moving workers. Empty returns are invisible to a product-only map but comprise half of the main-route worker travel in this case. Ancillary supply retrieval adds another 720 m before improvement. A layout assessment based only on the loaded product route would consequently miss much of the walking burden assigned to the handling function.

Distance reduction nevertheless does not establish ergonomic improvement. Load mass, push force, lift height, repetition, posture, and recovery opportunities are not represented. Bringing workstations closer could reduce walking while increasing stationary exposure or requiring more awkward transfers. Because the number of transfers is unchanged, no reduction in repetitive lifts follows from the model. This limit is substantive rather than a minor reporting qualification.

Similarly, a route-network figure cannot establish fewer traffic conflicts. Crossing points, arrival times, aisle occupancy, and interactions with powered vehicles are absent. A compact arrangement may concentrate movement into a constrained aisle. The study therefore treats congestion and safety as feasibility conditions outside the distance totals rather than assigning invented risk scores to them.

The analysis offers a practical reporting improvement: state the physical entity, travel boundary, frequency, and unit for every distance measure. In this example, 600 carrier-metres and 12,000 unit-metres describe the same improved loaded flow at different aggregation levels. Reporting either value simply as "material distance" would make comparison difficult and could create an apparent twenty-fold discrepancy.

Finally, the geometry-only alternative provides a cleaner interpretation of process relocation. The additional supply-placement benefit can be retained as a separate result instead of being hidden within a single percentage. This separation helps explain why another layout with the same product routes might deliver different worker movement. The difference could arise from tool storage and replenishment policy rather than from the process sequence itself.

9 Limitations and Conclusion

The route dataset is synthetic and contains no empirical worker trajectories. Consequently, the results quantify a specified scenario rather than demonstrate effectiveness at an operating facility. The model also excludes mixed product families, rework loops, variable container fill, and unplanned retrieval. Its equal return-distance rule is transparent but may not match multi-stop transport or opportunistic task chaining.

A further limitation is the absence of a dimensioned layout. The route values are not certified shortest paths through a measured floor area. Equipment clearances and access restrictions could increase travel or invalidate an assumed adjacency. This limits interpretation of the improved scenario to a design target and prevents any claim that the arrangement is ready for physical installation.

Within the defined boundary, loaded carrier-distance decreases by 56.14%, from 1,368 to 600 m per reference shift. Total defined worker-distance decreases by 58.33%, from 3,456 to 1,440 m. Route geometry alone produces a 44.44% worker-distance reduction; shorter ancillary supply trips account for the additional benefit. All results retain the original 72 loaded transfers.

The main conclusion is that movement evaluation requires separate accounting for material and people. A shorter product route can understate the total walking benefit when empty returns also shrink, but it cannot establish fewer handling events or safer work. A robust interpretation therefore reports both the distance change and the unchanged elements of the handling task.

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

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