NAC **Executive Insights**

Diseconomies of Scale

Key Points

- Traditional driving considerations related to economies of scale are considered.
- The need to relook at diseconomies of scale may be suggested by the performances of the largest and most complex projects.
- Diseconomies of scale are segregated into those arising from internal factors and those arising from externalities.
- Factors specifically impacting capital construction project scaling are provided.

Introduction

Bigger is not always better. In this Executive Insight diseconomies of scale are examined. Perhaps now is the time to reconsider fundamental decisions in capital project design.

Over the last several decades, the design and construction industry often gained efficiencies in cost and in performance as projects were scaled up. These so-called economies of scale have served the industry well. The challenges that scale presents and the complexity that comes with it, however, make it imperative that industry participants and stakeholders understand the implications of the decisions that are made in large complex projects.

Economies of Scale

Economies of scale broadly arise from labor and material efficiencies. A reduction in unit costs occurs as scale grows. For labor costs, economies of scale may be associated with the ability to sustain the labor force on site longer without needing to mobilize, demobilize, or move to another area. In addition, some labor indirects may be reduced on a unit cost basis as only one camp or set of crew facilities may be needed and staffed. Construction labor may further be reduced as the time to connect one large piece of electrical equipment may be no different than connecting a smaller one.

Material and equipment efficiencies may result from a piece of equipment not costing twice as much as one with half the capacity. Efficiencies may also result with larger volumes (tanks for example) not requiring twice as much steel as a tank with half the capacity would.

Estimates would typically develop scaling factors for each major component or cost category.

While the case for capturing economies of scale is compelling, it must be tempered by the realization that diseconomies of scale have always been present. Industry stakeholders and participants must understand the drivers of such diseconomies and the factors that contribute to them.

Diseconomies of Scale

Diseconomies of scale are often segregated into those arising from internal factors and those arising from externalities. Internal diseconomies of scale include those arising from:

- Poor communication – Communication challenges grow as organizations grow larger, adding layers with increased risks of inconsistent messaging. Poor communication can also arise as site-based workforces are spread out and as the number of suppliers and subcontractors grows.
- Lack of coordination – scale brings with it more work fronts, more work shifts, and larger crew sizes. These combine to challenge coordination both within and across crews and project teams.
- Limited employee engagement – scaling of the workforce may result in larger spans of control and a reduced ability to involve all members of the project team in workface planning and other more spontaneous or informal employee engagement activities. A degree of formality sets in.
- Loss of connectedness – as projects scale, additional layers of management are often introduced, creating more distance between the leadership team and line employees. This lack of connectedness impacts productivity, morale, and retention.
- Loss of speed – Decision making processes lose any sense of informality as more formal approval processes are established to provide a higher degree of control. This is further exacerbated by both the likely presence of additional management layers and a growth in specialized staff departments, which place emphasis on process over performance.
- Increasing fixed costs – larger project organizations involved with trying to achieve economies of scale are associated with growing fixed overheads (additional management layers; more elaborate processes and documentation; and specialized staff departments working with scale and complexity challenges as well as responding to project needs that come with scale.)
- Higher overheads and general conditions costs – overhead costs grow as staff and supplier requirements become more complex. Any local labor challenges may require introduction of incentives of various forms that normally are not required at smaller scales. Support resources that may have been available within the local community may now not adequately serve an expanded workforce (canteen; medical; transportation to site; and other infrastructure deficits that emerge)
- Managerial inefficiencies and diseconomies – these are associated with additional managerial layers; increased managerial coordination and training time; challenges with covering any expansion of shift work; and inefficiencies created with respect to training and supervision of any expanded crew sizes.
- Lack of morale/motivation of employees – this results from both reduced interaction with line supervisors and managers and loss of contact with the leadership team as additional layers are introduced. Employees lose a sense of belonging and commitment and increasingly feel isolated from a project's vision and goals. Organizational culture can suffer at scale.

- A high proportion of nonproductive employees – increased workforce size naturally results in a larger number of nonproductive employees. But the degradation of morale and the loss of a sense of belonging previously described further act to reduce productivity.
- Loss of clarity of management direction as number of layers increases.
- Inertia that grows with scale.
- Time lags in flow of information that impedes response – the "value of time" is not consistent throughout the various layers of the project organization or across a broadened expanse.
- Growing disadvantages of division of labor (over-specialization) – construction often requires contingent execution, for example, doing something earlier than planned because a scheduled activity is delayed. Overly specialized work crews limit the flexibility to undertake such execution.
- Loss of economies of scope – specialist resources become project dedicated vs project shared.
- Reduced economy of scope on company equipment if percentage of specialized equipment grows – this is not a material issue in the absence of specialized equipment. As scale grows, however, so too does the need for specialized equipment.
- Increased difficulty in realizing learning curve – learning is uneven across the workforce, driven by increased numbers of work crews, presence of larger proportions of specialized labor and equipment, and often challenges associated with lower labor retention rates. Lessons are often "observed" but not "learned."
- Infrastructure (company, project related) does not keep up (infrastructure inefficiency) – growth in scale begins taxing the capabilities and capacities of various company and project systems such as HR, accounting, procurement, quality assurance, risk management, logistics, and physical systems such as IT. After a certain level of growth, major investments are required to create the step change necessary to handle further increases in scale. This results in both cost and performance diseconomies.
- Increasing complexity – while not direct, scale and complexity have a strong relationship. Scaling often creates a step change in project complexity, narrowing the bandwidth available for risk mitigation as risks move into more significant areas. Complexity demands strengthened risk and quality systems that are often not accomplished by merely adding additional staff into these functional areas.
- Increasing communication challenges – the what, when, and how of communications changes as execution scales up. The number of potential communication paths grows exponentially as staff and key activities grow.
- Increased number of coordination and consultation points – scaling and growth in complexity require a more transparent supply chain with greater visibility of several supplier sub-tiers. The project team must engage, monitor, consult, and coordinate more deeply. This reflects the aggregation of risk that comes with scaling up. Management demands grow with scale and existing supply chain staffs and systems may require step changes to support scaling up. At some point the law of diminishing returns sets in. Further growth in scale comes with progressively higher marginal costs.

- Increase in capital inefficiencies with scale (longer time to first revenue; working capital lock-up; changed enterprise risk portfolios) – at the company level, bonding capacity may be tied up in larger amounts for longer periods of time.
- Increased sequential and complimentary activities (coupling and correlation) – scaling up may involve a larger number of conditions precedents for a significant activity to occur. Delays in any one condition precedent can impact a major, now consolidated activity, along with a larger potential for delay in a project. One other manifestation can be seen in delayed reviews and approvals as one large scale review may replace a dozen more discrete ones. Nothing can proceed until all are addressed by the one approval. This can be further exacerbated by staffing shortages in any one discipline or department with nothing able to move faster than the slowest path.
- Custom or bespoke designs limit the learning curve – the development of a unique design or solution at scale often has one replace many. Inherently the one goes through a normal learning curve associated with first of a kind or first of a series. When many replace one, there is a learning gain after the initial incidence. At some point scale and complexity grow and the more difficult learning curve outweighs multiple incidences that benefit from a strong learning curve.
- Project scale characteristics that appear to lower cost also lengthen the design and construction period – cost reductions must especially value any extended permitting, design, procurement, fabrication, inspection, or logistics time frames. Often the focus on cost is not balanced by a full consideration of all schedule impacts and associated costs.
- Standardization typically associated with economies of scale is often difficult to realize – absence of strong scope discipline often results in each subsequent copy "improving" on the prior version, thus negating many of the benefits from standardization.
- Longer schedules increase exposure to negative events – time is a risk aggregator.

External diseconomies of scale include those arising from outside the corporate or project organization and include factors such as:

- Shortage of skilled workforce
- Shortages of materials
- Increasing transportation and logistics costs – larger scale equipment or modules may strain existing logistical infrastructure and necessitate specialized handling equipment that may not be deployed as extensively as more common site equipment. In one example, as tank sizes increased, the logistics and transportation to get the tanks to the site increased, actually limiting the tank sizes that could be used. In a second case, highway bridge capacities on viable logistics routes became the limiting factor on module size.
- Congestion (site and logistical chain) – project scaling has an impact not only on the potential size of discrete elements of supply but also on total supply volumes. Two examples are worth noting. On one large project, over 100,000 workers came to the site every day. Congestion of access roads impacted overall productivity in a number of different ways. Congestion relief required the creation of multiple pick-up locations for site staff and the creation of a dedicated, scheduled bus service to alleviate road congestion. In a second example, a site with zero lay down area and a high demand of concrete, structural steel, and other foundation and structural

material required the implementation of a last-mile vehicle dispatch system and controlled staging areas so that required loads arrived in the right sequence within a 30-second window.

- Growing number of logistical links with trans-shipment – as a scale up occurs and a shift begins from materials of construction to fabricated items of supply ranging up to full modules, extended supply chains, sometimes global in nature, result. Such supply chains may include trans-shipment points at outbound ports, inbound ports, ship to rail, ship to barge, ship to road, rail to road, barge to road, and potentially last-mile trans-shipment to self-propelled modular transporters (SPMTs). Trans-shipment points represent transitional activities with limited control by the project team and the resulting elevated points of risk.
- Scale of energy (fuel) and waste flows – construction sites are major consumers of energy, much satisfied through the use of diesel fuel. As project sites scale up, fuel shipments to the site, if by truck, consume valuable, limited logistical capacity. Prefabrication and modularizations shift a portion of these logistics-consuming energy flows away from the final project site. Similarly, up to 25 percent of materials that arrive at the site leave as waste. As project scales grow, a workable solution may require more expensive step changes in solutions such as construction of a dedicated fuel pipeline or onsite waste consolidation or even processing facilities.
- Transaction cost growth with increased intermittent production – scaling of components to produce one large tank versus a series of smaller tanks, for example, can result in significantly higher transaction costs as well as production costs.
- Stretched supply chain – large scale projects often must reach further and compete harder to obtain the necessary materials of construction. This recently occurred when global supplies of steel (iron ore) and copper resulted in extended supply periods and significantly higher costs as competition for these materials in sufficient volumes accelerated.
- Limited suppliers at scale
- Increased exposure to extended construction period – this changes the quantification of risk.
- Infrastructure (industry, project related) does not keep up (infrastructure inefficiency) – road networks, power and water supply, waste and wastewater treatment, affordable housing and healthcare facilities, and staff all prove to be inadequate to meet project and project labor force needs. The project, as a minimum, may become a co-investor in needed improvements.
- Increasing complexity
- Increasing communication challenges
- Increased number of coordination and consultation points
- Increasing capital inefficiencies with scale (higher inventory levels) – routine supply chains may not have sufficient bandwidth or fidelity to operate the project in something akin to just in time supply. This necessitates the maintaining of inventories under the project's control in proximity to the project site. Inventories involve not only a carrying cost but increased exposures to theft and damage. Supply chain resources and efforts greatly exceed what one would expect on a smaller scale project. At some point, a tipping point is reached as more expensive solutions (barcode; RFID) are required.

- Increased sequential and complimentary activities (coupling and correlation) – coupling and correlation grow with the number of tasks and activities. Correlation measurably increases the risks a project will face.
- Custom made designs limit the learning curve as construction proceeds – improvement results from repletion. Scaling up in projects often strives to achieve economies of scale through a series of custom solutions. At some point, more is lost than is gained.
- Project scale characteristics that appear to lower cost also lengthen the construction period – this extension is often the result of process (including approval) complexity or logistics complexity as previously described.
- Increased stakeholder engagement and longer time frames for resolution of stakeholder issues.
- Standardization typically associated with economies of scale are difficult to realize as one-off designs and fabrication and installation specialization impacts constructability.
- Longer schedules increase exposure to negative events.

Factors Impacting Scaling Factor

Some factors that will impact scaling factors in capital construction projects that are construction unique include:

- **Labor productivity**
    - Site congestion
    - Required shift levels (staffing required on second, third, and weekend shifts) and durations (of shift work or scheduled overtime)
    - Reduced site logistical efficiency
    - Rework levels (caused by poor quality control; unplanned changes; out of sequence work)
    - Time on tool
    - Susceptibility to disruption (labor relations or agreements; work and environmental conditions; unsafe or unhealthy work environment; multi-cultural work sites)
- **Barriers to Productivity**
    - Expanding soft requirements (sensitivity and compliance training; increased documentation to satisfy expanded management layers and expanded staff departments and functions)
    - Inadequate valuing of time – time frames to make a decision outweigh the value that the decision creates (weeks of delay on the critical path of a multi-billion dollar project to optimize a $50,000 decision).
    - Serial specialization as barrier to systemic innovation (step changes in productivity require all elements of the supply chain to change in a new direction at the same time. Serial specialization often works against this need as each step in the process seeks to protect its own prerogatives.)
        - No competition of supply chains

    - Complexity leads to new risks
        - White space[1]
        - Black swans[2]
        - Coupled constraints[3]
        - Perceptions of challenges on scaling factors
    - Disaggregation of tool making from tool users
    - Means & Methods capture and sharing
- **Module efficiency**
    - Growing limitations on efficient module layout
        - Transport envelope limitations
        - Off module major equipment growth
    - Growth in site work/field construction activity
    - Logistical costs
- **Relative Labor Costs**
    - Field labor unit costs
    - Module yard labor unit costs
- **Project Elements Subject to Significant Scaling Advantages**
    - Extent of non-process infrastructure (NPI)
    - Extent of equipment by scaling factor
- **Relationship of Scaling Factor to Plant Availability**
    - Partial operation/shutdown capability
    - Demand following

Diseconomies of Scale in Action

Several factors in today's construction environment influence when economies of scale shift to diseconomies. These include:

- Adjustment of the number of units of "standard" labor (at base labor rate) by a reduction in productivity factor as the labor force expands and congestion of work areas grow.
- Performance of work at both the site and one or more module yards, each with different base labor rates of production, adjustment to productivity factors, and unit labor costs. Labor scaling factors are greater than 1.00 even as units of labor required may decline.

The reduction in the base labor amount will tend to scale (with a scaling factor less than 1.00) in relationship to overall capacity and equipment scaling factors[4]. At some point, labor units to be worked

[1] Executive Insight, White Space Risks, https://www.naocon.org/wp-content/uploads/White-Space-Risks.pdf
[2] Risks from Unknown Unknowns
[3] Executive Insight, Coupling in Large Complex Projects, https://www.naocon.org/wp-content/uploads/Coupling-in-Large-Complex-Projects.pdf
[4] A scale factor of less than 1 indicates that economies of scale exist and the incremental cost of the next added unit of capacity will be cheaper than the previous unit of capacity. When the scale factor is greater than 1, economies of scale do not exist; rather, diseconomies of scale exist and the incremental cost becomes more

will be offset by productivity losses. Any further scaling results in a diseconomy of scale with respect to labor.

In certain situations, the cost of specialized construction equipment, such as larger cranes, must be carefully considered. Such machines may need specially constructed pads for proper support.

Plant equipment (electrical and mechanical) will tend to retain its scaling factor at less than one, but as its scale increases it impacts labor scaling (negatively) and often introduces more expensive means and methods.

The following figure reflects tradeoff on one large project where the selection of installing a single large unit was advantageous if productivity rates could be maintained and not adversely impacted by congestion or other factors. As productivity dropped, diseconomies of scale came into effect, making an option for two 50% units more attractive.

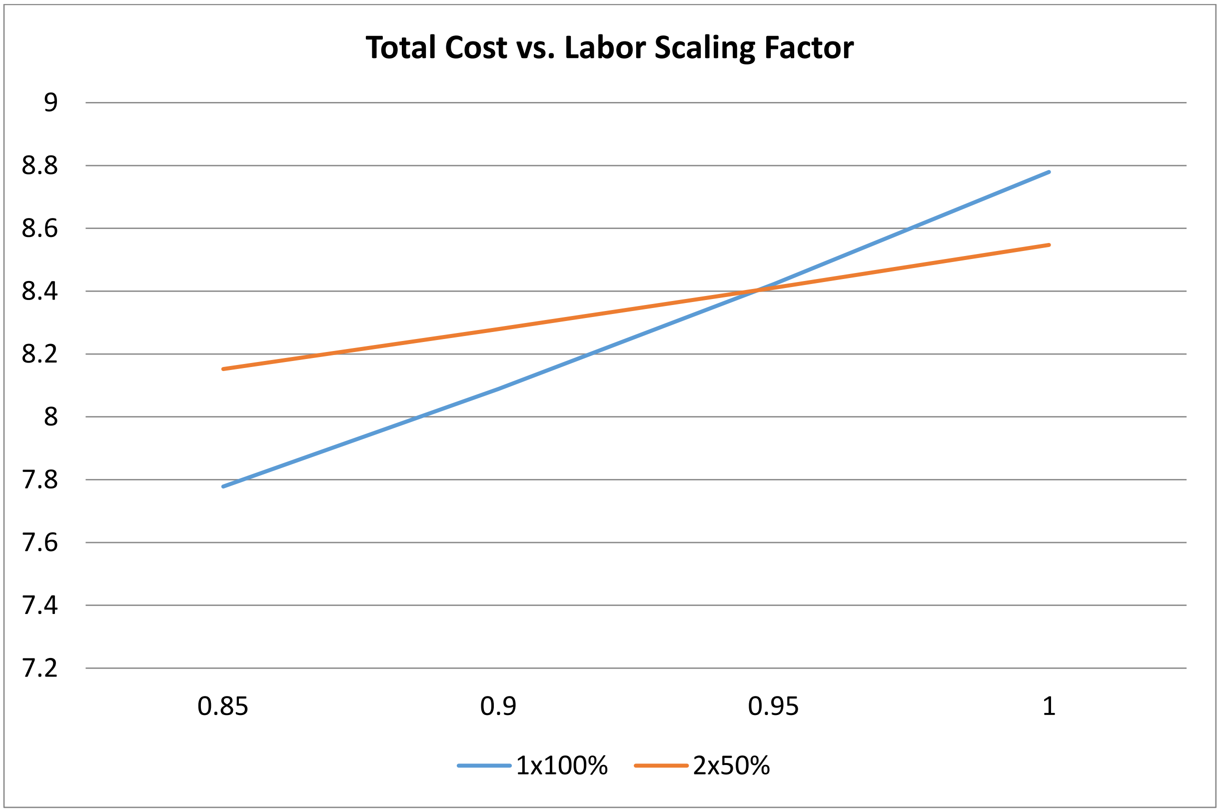

Figure 1. Diseconomies of scale after productivity dropped on a large project.

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expensive for every added unit of capacity. A scale factor of exactly 1 indicates that a linear relationship exists and there is no change in the incremental cost per unit of added capacity. A scale factor of 1 also indicates that it is just as economically feasible to build two small facilities as one large facility with the same capacity.

Too often economies of scale assessments ignore the impacts of factor-causing loss of productivity. The use of off-site construction (prefab and modularization) is one strategy to offset potential diseconomies by reducing site congestion both at the final location and in a modularization yard while reducing a component of labor cost.

Summary

Diseconomies of scale are real and need more attention in project cost estimating and operations planning. Detailed evaluations must consider the mix of labor (by type and location); construction means and methods changes as component sizes grow; plant equipment scaling factors for all major spend categories (cost per marginal unit); and materials of construction scaling.

In evaluating capital efficiency, the ability to bring partial capacity (one production line) on line earlier needs to be weighed in economic evaluations.

About the Author

Bob Prieto was elected to the National Academy of Construction in 2011. He is a senior executive who is effective in shaping and executing business strategy and a recognized leader within the infrastructure, engineering, and construction industries.