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EVALUATION**

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Abstract: *Aligning production capacity with customer demand is a critical challenge in manufacturing systems. Traditional evaluation approaches often lack the ability to dynamically assess multiple production scenarios and quantify demand gaps. This study presents a program-based TAKT-Based Throughput Capability Analysis (TBTCA) model, which integrates TAKT time with actual processing performance to evaluate demand feasibility. The proposed model is implemented using the Python programming language and enables structured, scenario-based analysis of production systems. A normalized capability index (TBTCA) is computed to classify system performance as demand-infeasible, balanced, or demand-capable. Additionally, the model quantifies demand gaps in terms of production shortfall or surplus. The results demonstrate that the developed computational model effectively identifies capacity constraints and evaluates improvement scenarios. The approach provides a simple, scalable, and data-driven tool for production planning and decision-making and can be extended to real-time industrial applications.*

Keywords: *TBTCA, TAKT Time, Throughput Capability, Capacity Planning, Demand Gap Analysis, Python Model*

1. Introduction

In modern production systems, the ability to meet customer demand consistently is a fundamental performance requirement. Conventional performance metrics such as utilization and efficiency do not directly indicate whether a system can satisfy demand. This creates a need for demand-oriented evaluation methods.

TAKT time is widely used in production systems to synchronize manufacturing output with customer demand. However, there is limited integration of TAKT-based evaluation with computational models that can analyze real production scenarios.

This study proposes a program-based TAKT-Based Throughput Capability Analysis (TBTCA) model, which compares TAKT time with actual production performance using a normalized index. The approach enables automated evaluation of production capability across multiple scenarios.

The primary contributions of this work include:

- Development of a computational TBTCA model.
- Integration of demand-driven evaluation with program-based analysis.
- Quantification of demand gaps for decision-making.

2. Literature Review

The concept of TAKT time was introduced as part of the Toyota Production System to align production rate with customer demand. Taiichi Ohno emphasized the importance of demand-driven production to eliminate waste and overproduction.

The Theory of Constraints developed by Eliyahu M. Goldratt highlights that system performance is governed by bottlenecks, reinforcing the need for throughput-based evaluation.

James P. Womack further extended Lean principles by focusing on flow, value, and demand synchronization in production systems.

Hopp and Spearman (2008) introduced the concept of Factory Physics, linking cycle time, variability, and throughput. Slack (2010) discussed the importance of capacity planning in maintaining production balance.

While existing research provides strong theoretical foundations, there is a lack of simple computational models that directly evaluate demand feasibility. The TBTCA approach addresses this gap by combining TAKT time with actual processing performance in a program-based framework.

3. Methodology

3.1 Mathematical Model

The TBTCA model is based on the following equations:

1. $CT_{\text{takt}} = T_{\text{available}} / \text{Demand}$
2. $t_{\text{actual}} = \text{Total Processing Time} / \text{FG Produced}$
3. $\text{TBTCA Index} = CT_{\text{takt}} / t_{\text{actual}}$

3.2 Interpretation Criteria

- **TBTCA < 1.00** → Demand-infeasible
- **TBTCA ≈ 1.00** → Near-balanced system
- **TBTCA > 1.00** → Demand-capable

3.3 Program Design

The TBTCA computational model is implemented using the Python programming language, enabling a structured and scalable approach for evaluating production capability under different operating conditions. The program is designed using modular functions and structured data representation to facilitate scenario-based analysis.

The model processes input data, computes TAKT time and actual processing time, and evaluates system capability using the TBTCA index. The detailed program implementation is not included for brevity and can be provided upon request.

The overall computational framework of the model is illustrated below. As shown in Figure 1, the computational framework consists of input, calculation, decision, and output stages.

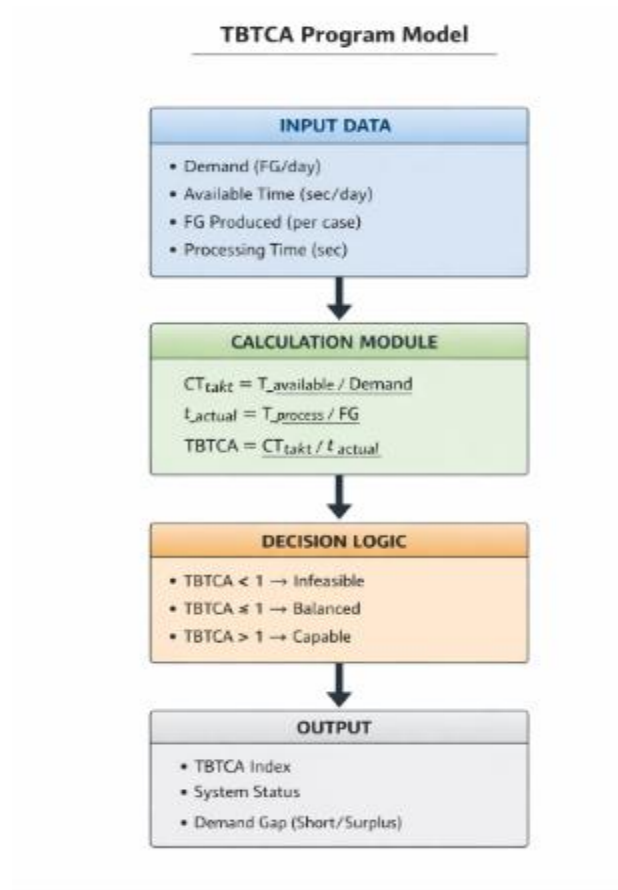


Figure 1: TBTC Program Model illustrating input parameters, computational logic, decision rules, and output generation.

3.4 Input Data

Table 1: Input Data

Parameter	Value
Demand	7500 FG/day
Available Time	75600 sec/day

Table 2: Production Scenarios

Case	FG/day	Processing Time (sec)
Before Lean	2340	75936
After Lean (Without OT)	7020	68276
After Lean (With OT)	8100	68276

4. Results

The TBTC model was applied to three production scenarios to evaluate system capability relative to customer demand.

Before Lean

- **TBTC = 0.31**
- **Status:** Demand-infeasible

- **Demand Gap:** 5160 units (Shortfall)

This indicates a significant mismatch between production capacity and demand, with the system operating far below the required throughput level.

After Lean (Without Overtime)

- **TBTCA = 1.04**
- **Status:** Demand-capable
- **Demand Gap:** 480 units (Shortfall)

The system shows substantial improvement and operates close to demand requirements. Although a small shortfall remains, the production capability is nearly balanced.

After Lean (With Overtime)

- **TBTCA = 1.20**
- **Status:** Demand-capable
- **Demand Gap:** 600 units (Surplus)

The introduction of overtime results in surplus production capacity, enabling the system to fully meet and exceed customer demand.

5. Discussion

The results demonstrate that the TBTCA model effectively captures the relationship between production capability and customer demand. A clear transition is observed from a demand-infeasible state ($TBTCA < 1$) to a demand-capable state ($TBTCA > 1$), indicating the effectiveness of system improvements.

The significant increase in the TBTCA index from 0.31 to 1.04 highlights the impact of process improvements in reducing cycle time and enhancing throughput capability. Furthermore, the increase to 1.20 with overtime confirms that additional capacity can be strategically introduced to create surplus production when required.

The model also provides quantitative insights into demand gaps, enabling precise identification of production shortfalls and surpluses. This is particularly useful for:

- Evaluating whether current capacity is sufficient.
- Determining the necessity of overtime.
- Supporting demand-driven production planning.

Overall, the TBTCA approach serves as a practical and effective tool for demand-oriented performance evaluation and decision-making.

6. Conclusions

This study presents a program-based TAKT-Based Throughput Capability Analysis (TBTCA) model for evaluating production performance relative to customer demand. The

model integrates TAKT time with actual processing performance to compute a normalized capability index, enabling direct assessment of demand feasibility.

The results demonstrate that the system transitions from a demand-infeasible state (TBTCa = 0.31) to a demand-capable state (TBTCa = 1.04 and 1.20) after improvements. This highlights the effectiveness of the proposed approach in capturing changes in production capability and identifying capacity constraints.

The developed model provides a simple, scalable, and data-driven framework for:

- Evaluating production capability relative to demand.
- Identifying shortfall and surplus conditions.
- Supporting decision-making for capacity planning and overtime.

Overall, the TBTCa model offers a practical computational tool for demand-oriented production analysis and can be effectively applied in industrial environments. The proposed model bridges the gap between theoretical TAKT analysis and practical computational implementation.

7. Future Work

The proposed TBTCa model can be extended and enhanced in several directions to improve its applicability and robustness:

- **Real-time integration:** Integration with shop-floor data systems (e.g., IoT sensors, MES) to enable real-time monitoring of throughput capability.
- **Dynamic demand modeling:** Incorporation of fluctuating demand patterns to evaluate system performance under variable conditions.
- **Predictive analytics:** Application of machine learning techniques to predict future demand gaps and capacity requirements.
- **Multi-line and multi-product systems:** Extension of the model to handle complex production systems involving multiple product types and parallel lines.
- **Decision support systems:** Development of a user-friendly dashboard or software tool for managers to visualize TBTCa results and make informed decisions.

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Conflict of Interest: The authors declare no conflict of interest.

Ethical Declarations: This study utilized production and process data provided by the participating company. No human or animal subjects were involved, and no personal data were collected. Therefore, ethical approval was not required.

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