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SMOOTHLY PASS THE PARCEL: IMPLEMENTING THE THEORY OF SWIFT, EVEN FLOW

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Abstract. This research examines the application of the Theory of Swift, Even Flow (TSEF) by a distribution company to improve the performance of its processes for parcels. TSEF was deployed by the company after experiencing lean improvement fatigue and diminishing returns from the time and effort invested. This case study combined quantitative and qualitative approaches to develop a good understanding of the operation. This approach enabled the business to utilise Discrete Event Simulation (DES), which facilitated the implementation of TSEF. From this study, the development of a novel DES application revealed the primacy of process variation and throughput time, key factors in TSEF, in driving improvements. The derived DES approach is reproducible and demonstrates its utility with production improvement frameworks. TSEF, through the visualisations and analysis provided by DES, broadened the scope of improvements to an enterprise level, therefore assisting the business managers in driving forward when lean improvement techniques stagnated. The impact of the research is not limited to the theoretical contribution, as the combination of DES and TSEF led to significant managerial insights on how to overcome obstacles and substantiate change.

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1. Introduction

This paper focuses on the flow of parcels through a distribution company's processes and the aspects of its operations that impede throughput. Improving the flow of parcels is more important than ever, given the continuing development of internet retailing and the concomitant increase in the volume of parcel shipments. Because of the frequency of delivery and the growth of final destinations, network entropy is increasing. Providing a cost-efficient and time-bound service under such circumstances is a significant test for any organisation engaged in distribution. This research explores the approach developed by a specific firm and its use of the theory of swift, even flow (TSEF) to develop enterprise-wide improvement facilitated by Discrete Event Simulation (DES).

The case study firm decided to adopt TSEF after 4 years of implementing lean principles with declining success and concerns about the sustainability of improvements achieved [1]. The lean campaign involved site-specific improvements that had failed to involve the wider process. The disconnect between lean implementation projects and business-wide strategic improvements has been evidenced by many researchers [2, 3]. Swift, even flow, on

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the other hand, enlarged the company's field of vision to include its end-to-end processes and unlocked savings across its organisational boundaries. This shift in perspective, for the case study firm, required some fundamental changes in management's view of productivity within and across organisational boundaries. Visualising the benefits of applying a TSEF approach was critical to the management team and the operators within the site. This contributed to the deployment of TSEF and enabled the researchers to empirically test the concept.

Two factors underpin TSEF: process variation and throughput time [4]. Improving both factors is expected to deliver competitive improvements across an enterprise [5,6]. DES was selected as the simulation tool to model and underpin the implementation of TSEF. DES is a prominent operational research tool, especially where scenarios are too complex, like in mail sorting centres, to gain meaningful insights using deterministic methods. For instance, Vrgoč and Čerić [7] used simulation to map and understand the parcel sorting operations to design optimal structures aiding the analysis and decision-making. Klomjit *et al.* [8], through simulation, demonstrated how to improve the efficiency of a parcel service company. Though DES has been deployed to model parcel flows, the authors are unaware of any previous work that has empirically applied DES to underpin the implementation of a theoretical concept such as TSEF. This gap in the literature is addressed through the contribution of this study.

Deploying DES to support the implementation of TSEF provided the researchers with an opportunity to empirically test the swift, even flow concept as an instrument for change, moving the idea from the realms of academia to the practitioners' arena. This manifests our method as DES and motivates the use of TSEF. Three key questions were asked in conducting the investigation: (a) Can TSEF breakthrough where lean principles become stymied?, (b) What is the role of DES in discovering process inefficiencies, validating the feasibility of change implementations, and saving costs? and (c) Does DES support TSEF as a business-level improvement tool?

The case study offers four pivotal insights: (1) the validation of the TSEF's process variability and throughput time factors as critical dimensions in improving business performance, (2) the presentation of a novel DES application to support TSEF implementation, (3) the development of the DES approach, which is reproducible and demonstrates its utility with production improvement frameworks, and (4) how the TSEF, through broadening the scope of improvements to an enterprise level, can assist business to drive forward when lean stagnates. The impact of the research is not limited to theoretical contribution, as the combination of DES and TSEF led to a nationwide change of operations and significant cost savings for the case study firm.

The next section reviews the literature about TSEF, DES, and relevant applications. This is followed by a discussion of the case study firm. Subsequently, the methodology used is explained, followed by a discussion of the discrete event simulation that was an important part of the implementation. After that discussion, the results of the implementation of TSEF are presented, and those results are then discussed in more detail.

2. Literature review

Researchers have used TSEF to investigate the cost and flow of patients through healthcare processes [9–11], to understand the performance of service firms over several years [12], development of circular economy manufacturing initiatives combining TSEF principles with lean practices [13] and to explain why some manufacturing firms operational performance provides advantages over their competitors.

Schmenner defines the Theory of Swift, Even Flow in this way:

> "The theory of swift, even flow states that two factors – and only two factors – are essential to productivity gain, no matter how one measures them. The first essential factor is to reduce variation. That variation can be of three types: quality, quantities, and timing. That is, one wants (1) to reduce defects and to perfect quality, (2) to even out the varieties of goods produced and the quantities of each so that each day of production resembles every other day of production, and (3) to produce with a regular timing or sequence to production. The second essential factor is to measure the time it takes to produce something from start to finish – its throughput time – and to reduce that throughput time as much as possible. Swift, even flow concentrates its attention on the flow of materials through a process; it asks people to

take the viewpoint of the materials moving through a process. By reducing the variation and throughput time of those materials, one eliminates the non-value-added aspects of production, which is where the cost and inefficiencies lie". ([4], p. 345)

Swift, even flow developed from Schmenner's empirical work on factory productivity. It is a theory that helps to explain how a variety of modern techniques and philosophies work as they do, among them lean operations, the theory of constraints, Six Sigma, and factory focus ([5], Chaps. 4 and 8). TSEF has been used to explain the huge leaps in productivity that accompanied the creation of the factory, the development of the continuous flow process, the moving assembly line, and other significant milestones in industrial history [4,6].

TSEF does not seek to diminish the power of the landmark lean paradigm [14]. Instead, it provides a rationale for lean operations, and for other concepts, such as factory focus, that can affect a company's entire supply chain. A *focused factory* has one (or two) overarching objectives (key manufacturing tasks) that allow an optimised process, usually with a narrower range of products. Focused factories can expect to outperform general-purpose production operations [15,16]. By so doing, TSEF can overcome a common weakness of lean implementation, namely bogging down within individual functions, which can limit lean progression and potential [6,17–20]. Several researchers highlight the potential for lean principles to be a boundary-spanning improvement approach. However, it is also noted that its occurrence as such is rare [17,21,22]. Driving improvement based on an enterprise-level process perspective overcomes the limitations of functionally driven, task-orientated, lean approaches that many organisations adopt [17,20]. TSEF provides management with a platform from which to envision and reconfigure the entire process, supporting the organisation in its drive for continuous improvement. Through better-integrated processes, TSEF can enable higher operational performance as bottlenecks and variability diminish [23].

Discrete Event Simulation is a valuable tool for understanding the flow of items through various process stages. More precisely, DES models the flow of entities through a system using discrete time steps created by state changes, where the state changes are triggered by events which often follow a random distribution [24]. This definition agrees well with the concepts we mentioned for the TSEF, such as "people taking the viewpoint of the materials moving through a process". Queueing systems such as the M/M/s [25,26] are a good example of modelling a process stage, where operational characteristics can be obtained analytically or through DES. Typical operational characteristics are the number of items and time spent in the queue, service or system [27]. These are used to identify bottlenecks, plan required capacity and allocate resources. Generally, DES is used in capacity planning to test theories about required resources [28]. This can relate to operational characteristics such as parcel volume, processing speed and number of employees. Bottleneck and process analysis are theoretical concepts substantiated by simulation analysis. DES identifies bottleneck effects, which are alleviated through process improvements. Additionally, DES can test scheduling theories to find improved shifts and workforce allocation. Most of these aspects will be explored in detail in our case study.

3. Case study firm

The case study firm is a European national distribution business focused on the sorting, distribution and delivery of high-volume parcels, among other items. The organisation is split into regions that operate as hubs for the processing of parcels from local, national, and international customers. Each region has transportation, sorting, and distribution operations. Even though these operations differ in size and complexity, they are linked by a common performance goal of delivering parcels anywhere within the country within 24–48 h, depending upon the service purchased by the customer. Delivery timeliness is critical in terms of customer service.

3.1. The process

The activities within the parcel process are triggered by a continuous stream of arriving trucks at the Operations Hub. Vehicles are unloaded, and the parcels are moved into the preparation area, where a rough filtering process puts them into trolleys for further processing. The preparation and sorting areas follow a schedule. The volume and timing of incoming parcels exhibit strong variations from day to day. The flow of incoming parcels could not be controlled in this study.

The sorting area at the Operations Hub consists of several identical machines that run in parallel. Parcels are transferred from the preparation area to the machines in such a way that the first machine is filled until it runs at full capacity. Only then are subsequent machines utilised. The machines are continuously filled with items to be sorted according to their destination location. The sequencing stage processes the sorted items in more detail on separate machines to deliver them efficiently to their final destinations. A sequenced batch contains the parcels in the order in which they will be delivered to end customers.

3.2. Characterising the operations hub and the distribution centres

The regional Operations Hub provided each of its Distribution Centres with parcels in two waves (batches) each day. At the Distribution Centres (DCs), the two sequenced batches were merged by hand before being processed further. The regions operated as independent entities that were measured on performance at a local, not a company-wide, level.

The Operations Hub could be characterised as follows:

(a) Mission: to turn the chaos of the arriving parcels into an orderly sequence of parcels that subsequent operations could use to deliver them to their destinations. The Operations Hub under study fed 20 Distribution Centres.
(b) Metrics: the major metrics used were "items per hour per machine" and "workers per machine".
(c) Issues: because of these metrics, the incentive was to keep the sorting and sequencing machines busy and always to process all of the parcels that had been received that day. This is why the Operations Hub provided each of the 20 Distribution Centres with parcels in two waves (batches).

Each Distribution Centre could be characterised similarly:

(a) Mission: to take the output of the Operations Hub and to sort the parcels into smaller batches for delivery by hundreds of delivery vehicles.
(b) Metrics: how quickly can the delivery people get their batches ready for delivery?
(c) Issues: because the Operations Hub fed each Distribution Centre twice during the day, the delivery people had to merge the two batches by hand. This involved much work and considerable space so that the final delivery sequence could be accomplished accurately. Delivery could not proceed until both waves of parcels were merged at the Distribution Centre. In essence, the Distribution Centre was forced to engage in sorting and sequencing itself.

3.3. History of improvement initiatives

For 4 years, the company had used a Japanese lean operations consultant and had deployed lean tools to make improvements to its operations at the major sorting hub under study (Fig. 1) [29]. The approach initially provided increases in labour productivity and equipment utilisation. However, early gains over the 4 years were not maintained, with overall equipment effectiveness (OEE) increasing initially by 3% and then falling back to 0.5% as the lean campaign continued.

The company's approach to improvement focused on its Operations Hub and not on its entire company-wide operations. Such an approach is commonly deployed by organisations engaged in a lean campaign [30]. Although implementing lean into parts of a process is a pragmatic and common occurrence [17], reducing the supply chain and its processes into its constituent parts, instead of taking an end-to-end process perspective, can obscure the causes of problems [31, 32]. The partial implementation of lean thinking within the company's functional silos had not engendered a lean philosophy across the entire business. Instead, it created islands of excellence [33].

Such localisation has been found to diminish the ability of organisations to sustain improvements [34]. The financial benefits delivered by the case study company's lean improvement approach had begun to dwindle over the 4 years, leading to questions about the sustainability and purpose of continuing.

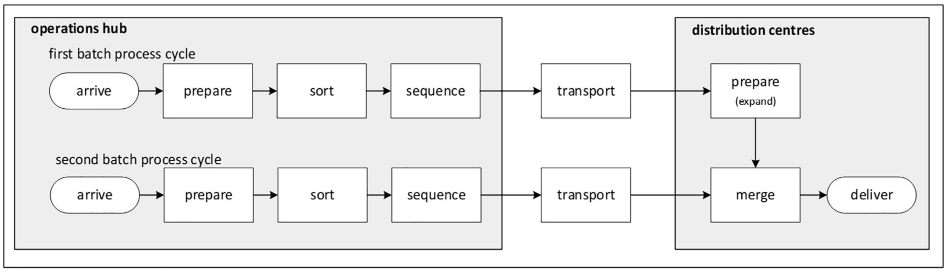


FIGURE 1. Process flow schematic (as-is scenario).

Recently, the company has been undergoing a series of modernisation activities due to a change in its ownership. This change in ownership prompted the firm to step up its improvement efforts. The first area selected for company-wide improvement was the distribution of small parcels. This project provided the opportunity for improvement in sorting, transportation, and distribution. End-to-end process changes across functional silos were recognised as offering potentially significant increases in cost and service performance. The operating hub and distribution centre management teams, which remained unchanged following the ownership change, were eager to address the limitations of localised area improvements and to move forward.

The researchers had initially been invited by the case study firm to investigate the organisation's approach to improvement after the lean campaign had begun to deliver diminishing returns. After discussions with senior executives, it became apparent that something more was needed to help the firm move forward with its continuous improvement initiatives. The management team was introduced to the concept of swift, even flow, and they read Schmenner's 2012 book [5].

Upon learning about swift, even flow and asking themselves the questions of where variation exists in the process and where throughput time bogs down, the company's managers hypothesised that there could be savings in transportation and handling costs by condensing the two process waves into one. They envisioned different strategic "missions" for the Operations Hub and each Distribution Centre. The Operations Hub's product would no longer be "waves" of sorted packages but a single sequenced daily batch of them. This batch would become the single input for each Distribution Centre. The Distribution Centres would no longer have to merge the batches. This simplified the missions for both operations. Management also realised that the metrics they had used for each location and the incentives that those metrics fostered had to be changed to unleash the potential of the organisation [15]. In academic parlance, two "focused factories" would be created in place of the more chaotic, overlapping situation that had prevailed.

Once this strategic insight was agreed upon, the managers' concern was whether the Operation Hub's capacity would be sufficient to process all parcels in a single batch. Changes in the initial sorting operation were expected to show up as financial gains in the subsequent transportation and distribution operations. This represented a marked change in approach as it would cross functional boundaries and require cross-party cooperation, an essential, strategic issue that the company's lean campaign had not addressed. Management would have to consider the flow of information and products across their sites to deliver the benefit. Doing so can be challenging because applying new approaches across organisational boundaries can result in resistance by employees [35].

We readily acknowledge that a different consultant could have advocated for the same action plan that is reported in this article. Nevertheless, an experienced Japanese lean operations consultant, in work spaced over 4 years, missed the opportunity that we recognised almost immediately using the theory of swift, even flow. It has been said that there is nothing as useful as a good theory, and for us, this case study provides another supporting example. This paper does not doubt the powerful track record of lean, but the firm had failed to progress with its lean approach [17]. However, the research emphasis here is on the usefulness of TSEF in providing a platform for change, including the strategic change embodied in the focused factory concept.

4. Methodology

Case study research supports "empirical research that primarily uses contextually rich data from bounded real-world settings to investigate a focused phenomenon" ([36], p. 329). Utilising a case study approach for deductive, theory-testing purposes within operations management is a fruitful methodological approach [37–39]. However, this case study research is not exclusively deductive. While TSEF provided the basic logic for the research questions posed, the data analysis and empirical findings exhibited inductive features. As Ketokivi and Choi ([40], p. 235) explain in their review of case study research, "Theory-testing is driven by theoretical deduction, but not exclusively limited to it".

The case study research design combined a quantitative and qualitative approach to gathering and analysing data [41]. Gathering a mix of quantitative and qualitative data enabled the research team to obtain a good understanding of the operation [42, 43] and a "synergistic view of the evidence" gathered ([44], p. 533). On the quantitative side, varied data collection methods provided strong substantiation of the theoretical model. Furthermore, three investigators were deployed, strengthening the confidence and credibility of the findings [36, 44]. Case selection is a critical step in case study research as it focuses the efforts of the investigators. Cases should be chosen that aid researchers to "replicate or extend the emergent theory" ([44], p. 537). By examining TSEF within a case study, the researchers had the opportunity to examine the concept using a business improvement approach. The details and criteria used to select the chosen case are as follows:

- It had actively pursued variability reduction in its processes. The organisation worked with lean tools and techniques, such as TQM, SPC, TPM, and 5S, for 4 years to minimise process variation against a background of high volatility in customer demand.
- It demonstrated an interest in improving its throughput time and, therefore, flow in its processes.
- Through the mapping of the process and the development of simulations and animations to visualise flow, the business itself identified opportunities for improvement.
- The case study company, as a result of changes in ownership, had begun to look at altering the flow of parcels across functional boundaries to gain end-to-end supply chain benefits instead of pursuing a traditional silo approach. With this change in its point of view, the company could potentially overcome the limitations of its "islands of excellence" experience by applying lean principles [17].
- It was willing to execute changes as a result of the research so that the researchers could observe changes to the processes and organisation as they unfolded.

4.1. Qualitative aspects

Data were collected through a multiple-method approach, including semi-structured interviews, observations and internal document reviews. Interviews were conducted with 16 people, ranging from senior group executives to front-line operators, across the Operations Hub and the Distribution Centres (Tab. 1 for details). Information on the views of the participants, as well as data on changes in performance due to the application of TSEF and factory focus, were collected from observations made at meetings and as the process was altered.

Quarterly review meetings were conducted with the steering committee in charge of implementing the changes. These meetings provided project updates as well as insights into technical and organisational issues. Senior management progress presentations permitted the project team to update management on progress and obstacles to implementation. These sessions helped to develop a standardised approach for the future implementation of TSEF and factory focus across other regions and sites.

These feedback sessions also provided an opportunity to triangulate our findings with the people managing and operating the processes, providing internal validity [9]. Following interviews, meetings and observations, the research team met to discuss and consider the challenges and successes that the organisation was experiencing. These post-meeting sessions allowed the researchers to work together to reach a consensus view of the progress and issues faced by the company.

TABLE 1. Interview details.

Role(s)	Duration and frequency
Hub management (including operations director, quality manager, improvement manager and logistics manager)	Interviewed between 60–90 min before and post-TSEF implementation
DC manager	Interviewed for 45 min before and 30 min post TSEF implementation
Hub shift supervisors (two), logistics supervisor and operators (one despatch operator and two parcel operators)	Interviewed between 20–45 min before and post-TSEF implementation
DC operators (two)	Interviewed between 15–20 min before and post-TSEF implementation
Group Management (Head of Design, Technical and Logistics)	Each interviewed for between 40–50 min post-TSEF Implementation

4.2. Quantitative aspects

Although the case study company's managers were open to the application of TSEF to their operations, some of them still needed convincing. Therefore, it was decided to embark on several quantitative exercises that could help the managers envision what the adoption of swift, even flow and focused factories could mean for them. To that end, data were collected directly from the case study firm and researcher measurements and observations. Historical data covering 2 years were gathered and analysed. Of particular interest were data on:

1. Demand – the delivery profile from day to day,
2. Quality – waste reduction, quality levels,
3. Bottlenecks – machine capacities, throughput rates, capacity constraints, and utilisation,
4. Scheduling and resource planning,
5. Variability – volumes, transport times, operations times.

Staats *et al.* ([42], p. 380) suggest that before investigating future changes, it is important to identify the previous "initiative's empirical performance" in a quantitative manner. Data was collected and assessed for reliability and accuracy. For example, researchers tested efficiencies and utilisation through observation and measurement. Although the recorded output data were found to be accurate, the standards used to gauge performance were found to be at variance with the machine manufacturers' published Data. Machines were found to be "slow running", and agreed performance standards were below the potential of the process, leading to inflated efficiency figures. These data provided the research team with an understanding of "true" performance changes due to improving flow and reducing variances. The overall case study has the following sequence: Case selected; Protocol and data collection; Data Analysis (simulation); TSEF Pilot and data collection; Discrete Event Simulation; Answering research questions; Literature comparison; and Research closure.

5. DISCRETE EVENT SIMULATION

In this section, we provide a detailed analysis of the problem and a methodological approach to applying the TSEF to the DES.

The goal of the simulation was to compare the current (as-is) model with the proposed (to-be) scenario so that the company's managers could see the advantages of the perspective taken by the theory of swift, even flow. The as-is structure is shown in Figure 1, and the to-be scenario is depicted in Figure 6. Specifically, the aim was to quantify the reduction of labour and the value-added process time. Furthermore, the effects on variation by removing the second process cycle can be observed.

The simulation design follows the classical phases. To begin with, the input data for the simulation was collected. This data was used to determine arrival rates, throughput rates and capacities for each process stage. Probability distributions [27] were fitted accordingly. The simulation was realised using a discrete event simulator, specifically the Rockwell Arena simulator. The appendix details the discrete event simulation implementation details, such as the processes, logical controls and specific stages. This offers complete transparency and reproducibility of the case study. Each process stage was verified independently. The simulation structure and results were validated by subject matter experts. This was done for each process stage and the entire process chain. The design of the experiments took into account sufficient variations of input, output and resources. Multiple replications were used to increase the confidence of the results.

To configure the simulation models appropriately, all essential process stages (Fig. 1) have to be analysed. The overall demand for parcels, which is the input and output, is the driver of the whole process. Thus, understanding and quantification are the first steps in the analysis (Sect. 5.1). The arrival of the "parcels" *via* trucks is explained in more detail (Sect. 5.2). The flow of parcels through the various process stages in the "as-is" scenario is specified and shown in Sections 5.3 and 5.4. These sections explain the technical details and measurements. In Section 5.5, particular emphasis is given to timing. The timings suggest the feasibility of combining duplicated process stages (cycles). This is confirmed with the "to-be" simulation scenario (Sect. 5.6). Further, this improved process flow leads to cost savings.

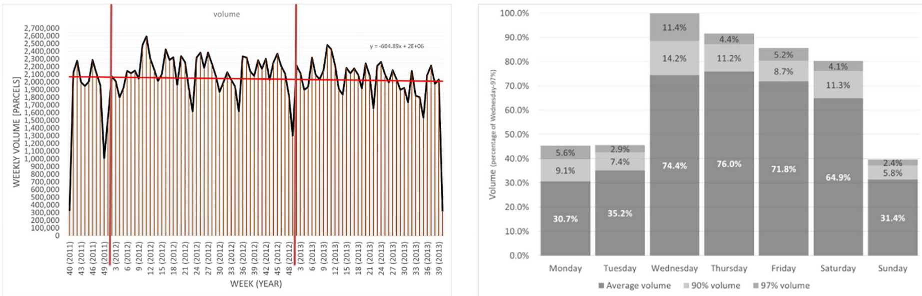
5.1. Incoming demand and daily profiles

The number of items received by the sorting centre daily was recorded over almost 2 years (98 weeks). The weekly volume was 2.04 million parcels, on average. A linear trend analysis indicated a year-to-year decline in parcel volume of about 2.1% (Fig. 2a). The weekday profile is shown in Figure 2b. The figure highlights that Wednesday is the "heaviest" day. Therefore, special attention was given to that day, and all weekdays were normalised based on its 97% quantile expected volume. A 3% service-level violation on the heaviest day was seen as more than acceptable by the practitioners. That means we expected that 97% of all Wednesdays would have a volume that is less than 525 979 parcels. On average, a Wednesday has 411 689 parcels (normally distributed with a standard deviation of 75 123 parcels). To get an idea of service-level volumes, we determined the 90% and 97% quantile parcel volumes per weekday in addition to the average volume. The 90% quantile parcel volume was directly derived from the sample of 98 weeks, whilst the 97% quantile was based on a normal distribution assumption. Given the above Wednesday data, other absolute quantities can be derived. For instance, Tuesday's average volume is 35.2% $\times$ 525 979 parcels = 194 649 parcels. The profile analysis highlighted the variability of demand in terms of weekdays and arrival times. It showed that if there was sufficient capacity in the sorting centre and distribution centres to deal with Wednesday demands, then the other weekdays could be accommodated as well. It can be seen that a potential solution to improve the flow of parcels through the process chain would have to be able to operate under significant variances in demand across the week. The nature of the demand suggests that the operation can be designed as a pull system ([45], p. 656). A strategy of levelling out the daily demand variations cannot be implemented due to the company's service agreements.

The normal distribution has been found by fitting the data to several classic distributions (see Appendix for details). The choice of the normal distribution is theoretically motivated by the high number of independent observations, the large volume and the low coefficient of variation [46]. An additional advantage of choosing the normal distribution is the ease of deriving and explaining service levels.

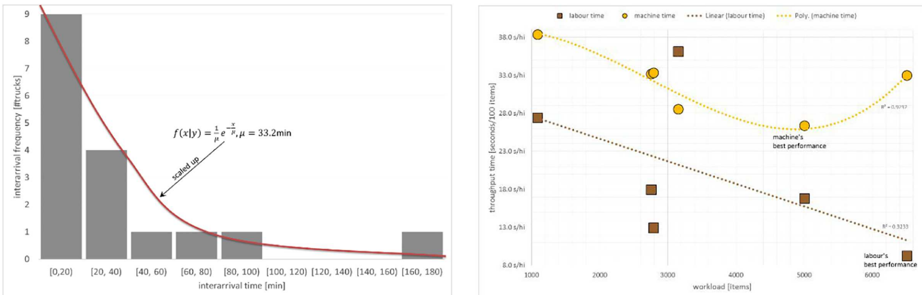
5.2. Incoming parcel arrival stream

The above volume is delivered to the sorting centre *via* trucks with varying loads. Inter-arrival patterns of trucks are shown in Figure 3a. The 17 observations took place between 6:40 pm and 4:05 am and were confirmed *via* 9 weekly repetitions. It was assumed that the obtained pattern was representative of each Wednesday and could be extended to a 24-h time frame.



(a) (b)

FIGURE 2. (a) Demand/weekly volume time series; (b) weekday profile.



(a) (b)

FIGURE 3. (a) Inter-arrival time distribution of trucks; (b) sequencing labour and machine throughput times.

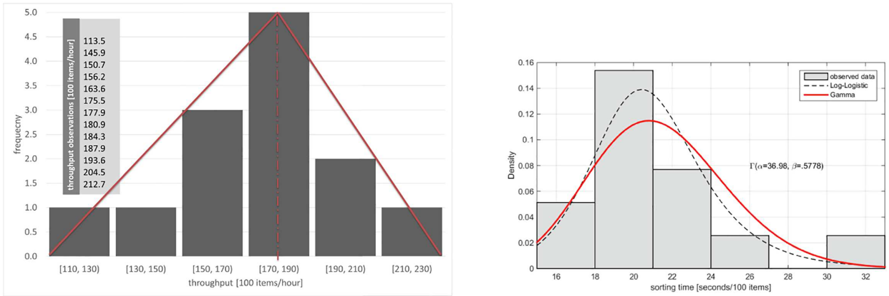
An exponential distribution was fitted to the data, giving a maximum likelihood estimate of 33.2 min for the mean. Thus, we expected 43.4 trucks (using Little's Law $N = \lambda T$) over 24 h to carry an average load of 412 000 parcels. A truck carries, on average, 9492 parcels with a standard deviation of 1732 parcels (normally distributed, derived from the overall demand and the nine observational repetitions).

Arrival processes are commonly modelled using a Poisson process, implying an exponential distribution [25], which is known as a memoryless process. The mean arrival time of approximately 30 min was also observed by Bartholdi and Hackman ([47], p. 24) for trucks arriving at warehouses.

5.3. Throughput rates and capacity

The *throughput rate* is defined as the number of items that are processed to completion during a specified period. The *nominal (design) capacity* is the maximum achievable throughput rate under ideal workload conditions. The *usable (effective) capacity* is the average achievable throughput rate under "typical" (high) workload conditions. Here, the *service rate* will be defined as the usable capacity. *Utilisation* is defined as actual throughput and is a percentage of nominal capacity. *Efficiency* is the actual throughput as a percentage of usable capacity.

The firm investigated the application of TSEF to its Operations Hub and Distribution Centres specifically to reduce variation and improve throughput time. To this end, the throughput rate for each process stage was measured. The challenge here was converting different batch units, *i.e.*, finding the "smallest" common entity. In the beginning, the units of arrivals are truckloads. These units are transformed into cage trolleys, followed by items (parcels) for analytical consideration. The analytical considerations were primarily based on throughput



(a) (b)

FIGURE 4. (a) Observed throughput for sorting; (b) fitted sorting time.

rates (λ), volume (N) and time (T). The relation of these measures can be expressed using Little's Law:

$$N = \lambda T. \tag{1}$$

The throughput rates for all process steps were determined. The analysis of available and necessary times for each process step showed that sequencing was the critical process step because the machines can only start once the items have been sorted. Interestingly, this is due to the nature of the process rather than its performance.

Throughput rates for all process steps were determined based on actual observations rather than the machines' specified maximum throughput rates. As indicated in the above definitions, the provided workload at each process stage (*i.e.*, the fill factor of buffers/queues) is essential for the actual throughput. That means random arrivals without sufficiently filled item buffers lead to significant drops in the throughput rate at a process stage.

5.4. Sorting, sequencing and merging process stage characteristics

Several sorting machines (4–6, average: 4.85), including the operating personnel, were observed. Thirteen observations were made over 87 days. Each observation analysed a planned run of 5 h. Figure 4a displays the operational throughput rate observations.

The variability is mainly due to human interaction in the feeding process or when removing full cage trolleys. A gamma distribution with parameters $\alpha = 36.98$ and $\alpha = 0.5778$ with a log-likelihood of -34.7 was fitted to describe the service times (Fig. 4b). This leads to an average sorting machine throughput of $\lambda = 15\ 157$ items/h with an average total processing time of 5.51 h for all five machines. The overall throughput rate for sequencing varied between 5475 items/h and 8536 items/h per machine. Figure 3b shows the corresponding labour (preparation and destack time) and machine (three passes) throughput times for the sequencing stage, as well as the workload (volume of parcels).

This indicates that a higher volume of parcels can be prepared by human resources than is required in the subsequent machine stage. Labour's service time was approximated by fitting an exponential distribution with a mean of 11.1 s plus a 9-s offset. The machine performance depends on the workload, as Figure 3b shows. The machines' best performance (26.4 s for 100 items) was used as the nominal capacity (assuming the ideal workload). Further, this capacity will be used to describe the machine's maximum service rate. The workforce required to feed the machines has a higher throughput rate than the machines (Fig. 3b), indicating possible resource savings and a further reduction in process speed variations.

The merging process stage takes place in the distribution centres. The directive is that a person should process (merge) 32 items per minute. However, the actual observations showed that a worker has an average throughput of 11.3 items per minute. Non-standard and variable approaches to executing the sequencing tasks were found to diminish the throughput rate. For example, operators would operate differently in terms of preparation for merging. Some would organise their parcels to be closer to the workstation before work commences, whilst others

TABLE 2. Service time/rate probability distributions of essential process stages.

Process stage	Distribution	p1	p2	p3	Unit	Arena expression
Daily volume	Normal	$\mu = 4116.9$	$\sigma = 751.2$		100 parcels/day	
Truck arrivals	Exponential	$\lambda = 33.2$			min/truck	EXPO(33.2)
Load per truck	Normal	$\mu = 94.92$	$\sigma = 17.32$		100 parcels/truck	NORM(94.92,17.32)
Preparation	Uniform	a = 3.375	b = 4.125		s/100 parcels	UNIF(3.375 , 4.125)
Sorting rate	Triangular	a = 113	c = 180	b = 213	100 parcels/h	
Sorting time	Gamma	$\alpha = 36.98$	$\beta = 0.578$		s/100 parcels	GAMM(36.98, 0.5778)
Seq. time - labour	Exponential	$\lambda = 11.1$		c = 9	s/100 parcels	9 + EXPO(11.1)
Seq. time - machines	Constant	c = 26.4			s/100 parcels	26.4
Transport	Uniform	a = 20	b = 40		min/100 parcels	UNIF(20, 40)
Merging	Normal	$\mu = 9.1$	$\sigma = 1.82$		min/100 parcels	NORM(9.1, 1.82)

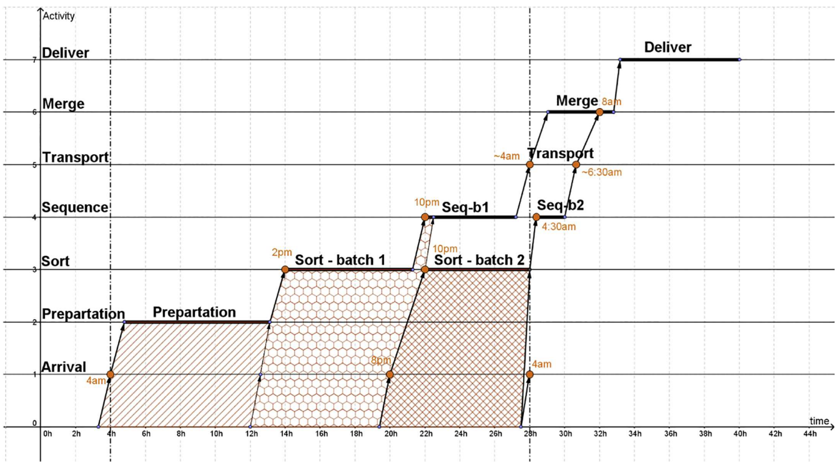


FIGURE 5. Time-activity diagram.

would prefer to walk between the loading bays to collect their parcels during the merging period. In total, 515 workers are available in all the distribution centres. Table 2 summarises the found service time probability distributions of the entire process chain.

5.5. Timings and process flow

Figure 5 shows the essential activities and their respective timings for the two batch process cycles. Transitions between activity timelines involve storage and movement. As explained above, a truck arrives on average every 33.2 min (varying arrivals and workloads). The first truck arrives at 4 am, and arrivals continue until the cut-off time of 8 pm. The time window [4 am, 8 pm] of 16 h defines the first batch. Once it is 8 pm, the volume for batch 1 is known. The second batch run covers the remaining 8 h and completes a full daily cycle irrespective of the day of the week. At 4 am, the actual volume for the day is known (Fig. 5). The received items are unloaded and prepared in a dedicated area. The systematic preparation is discontinued at 1 pm and substituted with an ad-hoc preparation at the sorting machines.

The sorting process starts at 2 pm and stops at 10 pm. Here, a complication can occur when items cannot be fed into the sorting machines. Usually, these are small amounts which are dealt with manually before sequencing starts. The criteria used to start the sequencing process varied occasionally and were based on the utilisation of

TABLE 3. Durations, resources and costs per activity.

Activity	Batch	Duration				Resources		Planned cost			Simulated busy cost		
		Start	Plan	Sim.	Diff.	PR	HR	Total	PR	HR	PR	HR	Diff.
Arrival & prepare	Batch 1	04:00	16.00	16.00	–	–	3	720	–	720		66	1014
	Batch 2	20:00	8.00	8.00	–	–	3	360	–	360			
Sort	Batch 1	14:00	7.00	5.61	1.39	5	5	1295	770	525	555	378	1379
	Batch 2	22:00	5.50	5.51	−0.01	5	5	1018	605	413			
Sequence	Batch 1	22:00	5.00	4.01	0.99	6	6	1110	660	450	686	356	401
	Batch 2	04:30	1.50	1.70	−0.20	6	6	333	198	135			
Transport	Batch 1	04:00	0.50	0.48	0.02	20	20	370	220	150	424	289	27
	Batch 2	06:30	0.50	0.48	0.02	20	20	370	220	150			
Merging	Batch 1	05:00	0.75	0.98	−0.23	–	515	5794	–	5794	9669		−13
	Batch 2	08:00	0.50	0.55	−0.05	–	515	3863	–	3863			
Delivery	All	09:00					515	–	–	–			
	Total	*29*	*45.3*	*43.3*	*1.9*			*15 232*	*2673*	*12 559*	*11 334*	*1090*	*2808*

workers and the capacity of the equipment. Success for the area was assessed on the overall equipment efficiency per machine based on running time and labour efficiency, not the achievement of the schedule, which was a plant-level measure. This view mistakenly thinks that labour efficiency is indicative of productivity [4, 15].

The sequencing stage for small parcels operates as a batch operation. The sequencing machine group was identified in the study as a bottleneck in the supply chain and, therefore, a limitation to increasing the throughput of the machines. The researchers observed that certain machines were operating at full capacity intermittently whilst others ran at a lower level consistently. Some operators would fully load the equipment for short periods and then leave the area to collect further parcels or have unplanned rest breaks. Others would ensure that a sufficient workload was available to support a constant volume over the allocated period. Both approaches, reminiscent of the tortoise and hare fable, eventually produced the planned output. The observations highlighted the non-standardised work procedures across the area. Issues of employees failing to adhere to standard operating procedures, therefore diminishing the power of lean, were a common occurrence.

The sequencing stage is followed by a transportation activity, where trucks distribute the items to the corresponding distribution centres. Here, a fleet of 20 trucks and drivers was used, and travel times varied with an average duration of approximately 30 min. These transportation journeys start at 5 am for batch 1 and at 8 am for batch 2. In the distribution centres, the merging occurs with an aggregated workforce of 515 people. The planned durations are 45 min and 30 min for batches 1 and 2, respectively. Table 3 summarises all the activities and their duration characteristics. It also shows the associated resources and costs.

The resources are divided into physical resources (PR) and human resources (HR). The number of available (or assigned) physical and human resources are abbreviated with n_p and n_h, respectively. For instance, the transport activity from the operations hub to the distribution centres requires $n_p = 20$ trucks and $n_h = 20$ drivers. The planned cost for using 20 trucks for half an hour is determined by \$22/h $\times$ 0.5 h $\times$ 20 trucks = \$220. Roughly spoken, the busy cost is the product of resource cost, busy time and several busy resources. A more precise formulation is:

$$\sum_{\Delta t \in T} c\Delta t, \tag{2}$$

where Δt is the time interval a resource is used for servicing, c is the cost for using the resource, and T is the set of all time intervals (which can overlap). The simulated busy cost is the busy cost but with Δt used from the simulation (abbreviated with Δt_s). Note that:

$$\sum \Delta t_s < (d_{s1} + d_{s2})(n_p + n_h), \tag{3}$$

where d_{si} is the duration obtained by the simulation for batch i.

The previous subsections have given a detailed explanation of the current scenario and raise the question: Is it possible to combine the operations of batches 1 and 2?

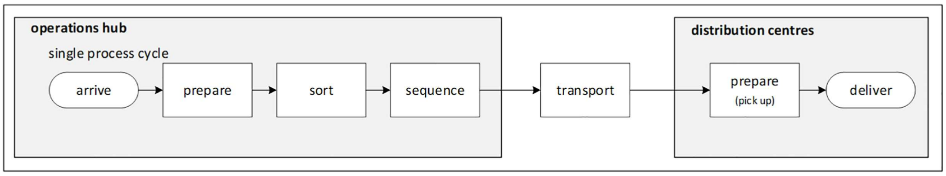


FIGURE 6. Optimised process flow (to-be scenario).

TABLE 4. Results of simulated to-be scenario.

Activity	Start	Duration			Resources		Planned cost			Simulated busy cost		
		Plan	Sim.	Diff.	PR	HR	Total	PR	HR	PR	HR	Diff.
Arrival & prepare	04:00	24.00	24.00	–	–	3	1080	–	1080		66	1014
Sort	15:30	11.12	12.08	−0.96	5	5	2057	1223	834	544	371	1143
Sequence	02:40	5.71	5.62	0.09	6	6	1268	754	514	670	349	248
Transport	08:05	0.48	0.48	0.00	20	20	355	211	144	210	143	2
Pick-up	08:35	0.19	0.19	0.00	–	515	1468	–	1468	1211		257
Delivery	09:00					515	–	–	–			
Total	*29*	*41.5*	*42.4*	*−0.9*			*6228*	*2188*	*4040*	*2634*	*929*	*2664*

5.6. To-be scenario

This sub-section will show that sufficient resources are available to allow a single batch run. The To-Be scenario (Fig. 6) simplifies the As-Is scenario (Fig. 1) by combining the two batches.

The perceived bottleneck in the area was not machine capacity but scheduling. Labour would be scheduled to move between sequencing equipment and another area of the plant to balance the workloads across the different areas. The shift manager explained the logic behind this approach as a "balancing act". While the small parcel area waited for the next batch to build up, the operators could be gainfully employed and work in another part of the business to ensure high labour efficiencies. "We work in two cycles as this is a more efficient use of labour. While we wait for the next batch to build up, we move labour to prep work in the large parcels area," stated a supervisor. However, the perceived "efficient" use of labour did not improve the throughput time for sequencing small parcels. Focusing on and improving labour and equipment efficiencies had no impact on the overall throughput time of the process and its potential competitive advantage [15].

The to-be scenario details are shown in Table 4. The activities are a subset of the as-is scenario. They range from the arrival and preparation of parcels to delivering them.

It can be seen that activity durations overlap, which supports the importance of using simulation rather than average value calculations. In this scenario, the arrival and preparation at the operations hub is continuous throughout a complete day cycle (24 h) rather than being split up into a 16-h and 8-h batch (as done in the as-is scenario). To find appropriate activity start times of operations and transportation, the latest allowed delivery time (9 am) at the distribution centre is the starting point for calculations. The expected durations (in the above table "plan" columns) are obtained by using the throughput rates found in the previous subsections. Backtracking these durations leads to the specified start times. Simulations allow further refinements of the anticipated durations because of their ability to consider the whole process chain's random behaviour (variations). The averages from multiple simulation runs were used in the "sim" column. Another advantage of DES is the availability of resulting probability distributions for service-level considerations. It is recommended to use those values rather than the "plan" values. For instance, it can be seen that the simulated sorting duration is about an hour longer than the planned duration, which is a more reliable measure. However, the overall duration of the to-be scenario is similar to the as-is scenario (2.2% difference). The cost savings are substantial. The planned cost savings are 59.1% using the to-be scenario ($6.2 k/day) rather than the as-is scenario

($15.2 k/day). The planned costs assume that the personnel has to be paid even when resources are not adding value. The busy cost focuses on the value-added services only. The busy cost (value added) savings are 71.3%.

A closer investigation of the tables reveals that these savings were mainly due to removing the excessive labour cost that was caused by the manual merging process.

The unevenness of flow in the small parcel area was a result of resource planning, labour and machine utilisation, and non-standardised work practices, not machine capacity. By running in two batches, management optimised machine running efficiency and delivered against their KPIs for utilisation. This also meant that the sequencing operation, due to sufficient buffer capacity (time), did not lead to any blockage in the preceding upstream process steps. The downstream supply chain, however, experienced "starvation". The manual merge area at the Distribution Centre received parcels in two batches. This meant that unloading vehicles and handling products would occur twice. The first batch would be unloaded and reside in the merge area until the second delivery of parcels arrived. This led to space problems, particularly around peak periods such as Black Friday and Christmas, as operators would have to manoeuvre around their work-in-progress parcels until such time that they could execute the merging activity.

Smoothing the flow of work through the sequencing area was expected to provide a continuous volume of products across the supply chain. This was expected to reduce transport costs between the operations and result in fewer process delays, less duplicate handling, and unnecessary motion. However, achieving these benefits would require a change in not only the planning of resources across the supply chain but also the key performance indicators (KPIs) used to drive performance. To achieve the support required, the project team mapped and analysed the processes leading to the development of simulations and animations to explain and show the potential benefits of the changes.

6. Implementation results

The data analysis for each process stage identified essential statistics on volume and time distributions. The implementation results are summarised in Table 2. The findings highlighted that the normally distributed daily volume was experiencing a 2.1% yearly decline. This insight allowed the operations management to forecast the demand and develop confidence in the intended service changes. The identification of the weekly profile and the usage of the demand for the heaviest day assures management that process changes are feasible and achievable at the required service level. The design/dimensioning of the process was based on a 97% service level (Fig. 2). And, because of the forecasted reduction in future volumes, the service level will be even higher in the future.

The visualisation of the as-is simulation scenario in the simplified schematic shown in Figure 1 caused the questioning of the need for the second process cycle. All previous lean approaches were only applied to the operations hub but missed out on the detrimental manual merging step within the distribution centre, believing it to be a necessity due to capacity constraints within the operations hub. The TSEF promotes an even flow rather than a "stop-and-go" approach caused by repeating process steps twice. The collected data, its analysis and simulation demonstrated to the case study firm that condensing the two cycles of parcel sorting, as shown in Figure 6, was both feasible and desirable. This reduces the waiting time for parcels in the process and smooths the flow. The important aspect to consider was the runtime of the sequencing step, which can be derived from Little's Law using the throughputs from Table 2. The average throughput rate was 7128 items/h per sequencing machine, a rate sufficient to handle most periods. This visualisation of the process led to the decision to proceed with the project and implement the principles of TSEF.

Given this analysis, the two sequence cycles were combined, leading to cost savings in transport and labour between the Operations Hub and the Distribution Centres. *The significant cost reduction was in the Distribution Centre (over 90%), whilst most of the changes in process and working practices occurred in the Operations Hub.* Smoothing the flow across 12.5 h by removing the batching approach to sequencing resulted in the eradication of the merging activity in the Distribution Centre and reduced transport movements.

Through piloting the new way of working, the savings demonstrated by the simulation (Tab. 4) were beginning to be realised. However, they were not fully matured before our study finished. Savings, as expected, were mainly due to removing the excessive labour cost that was caused by the manual merging process. Further, the condensing of the two batch cycles into a single even flow annualised savings of 106 000 travelled kilometres and a saved travel time of 2117 h, based on the pilot, for the Distribution Centres was being projected. Labour savings due to the change in flow were significant, resulting in a redistribution and refocus of labour to improve the service offering and frequency of deliveries to major population centres. Thompson [48] showed that controllable work improves labour utilisation, which was confirmed during this project. Furthermore, rejected parcels from the Operations Hub that were manually handled by the Distribution Centres were reduced by 1.5% in terms of volume, leading to additional savings. Minimisation of rework improved the flow of parcels through the supply chain and reduced the effort required to handle them as operational failures diminished. Operators recorded a reduction of over 60% in time wasted travelling between goods-in and final despatch.

7. Discussion

These empirically grounded findings show that the application of TSEF can indeed improve the performance of a services-based organisation. To make it work, however, several inhibitors to reducing variation and throughput time improvement had to be overcome. In this section, we address those inhibitors: (i) silos, (ii) inappropriate performance measures, (iii) lack of vision, and (iv) sources of variation.

Toppling silos. One of the major impediments to developing a TSEF approach was the organisational structure that existed within the case study firm. Historically, managers devoted attention to their immediate area of responsibility. Such a silo perspective limited understanding of the enterprise-wide improvements that could be implemented [17,49]. Functional orientations reduced both the flow of information and the end-to-end process data that could be used to optimise the flow of value across the organisation. Silos also minimise internal coordination, and that hinders the ability of a firm to manage demand fluctuations [11]. This silo problem surfaced in this case with the cancellation of several meetings between the TSEF project team and the DC. The director had to intervene. "Resistance from managers there [DC] delayed the implementation. Once we could explain and show the benefits, this improved. We are just not used to talking about working together to make improvements", explained one project leader from the Operations Hub. Reducing organisational barriers and developing an end-to-end perspective that can drive flow across functional boundaries was critical to implementing TSEF.

The change in ownership created the impetus for improving flow and developing an inter-organisational improvement perspective. Harmonising activities end-to-end improved the decision-making within the entire organisation. Skinner ([15], p. 56) highlighted the importance of altering the "approaches in materials and workforce management" as critical to unlocking the competitive advantage of a factory. Cross-site teams were established to support enhanced communications and information sharing across supply chain boundaries. "Creating a single batch run will deliver substantial savings across the pipeline of our entire business", stated the head of design for the group. The management of the company recognised that current work practices and governance structures could be limiting the organisation's opportunities. This aligns with the argument of Bamford *et al.* [17] on the development of lean that full adoption of the concept requires the removal of "restrictions and blockages to progress". By adopting TSEF and building upon the benefits of previous lean projects, management enabled company-wide improvements to be made.

Overcoming inappropriate performance measures. Altering the flow across the company required the case study firm to create new metrics because the historical approach, which had been the foundation for improvement, was no longer appropriate. Operationally, the case study firm concentrated on increasing efficiency when the machines ran by maximising loading for discrete and unconnected periods. This surging approach was driven by KPIs such as Overall Equipment Effectiveness (OEE) and labour efficiencies, which measured output when the machine ran. The weaknesses of a productivity approach that focuses tightly on the efficiency of workers through the application of more stringent controls "detracts attention from the structure of the production system itself" ([15], p. 56). Achieving improvements in the evenness of flow requires management to focus on measures of variability and throughput time reduction, not labour and machine efficiencies [10,11]. Our findings align with the view of Onofrei *et al.* [6], Schmenner [5] and Skinner [15] that measures of performance are important. However, they can be misleading if not used to drive appropriate supply chain and factory improvements.

Moving beyond the modus operandi of incremental lean improvements required a "deal breaker," stated the Operations Hub director. By utilising a TSEF perspective, the company recognised that an end-to-end process change would not only deliver significant benefits but would also widen the influence of its lean ethos [17]. Using TSEF to envision what process should be permitted the case study firm to concentrate on increasing value and eliminating waste. The resulting company-wide improvement plan (*i.e.*, focusing the factories) built upon previous successes.

Using simulation to aid vision in managers. The case study‘s use of DES and animations demonstrated to the organisation the potential of looking at supply chain-level improvements. Realising the potential of TSEF required visualising the flow of parcel distribution. For services, developing a map that engages, is dynamic, and represents the flow of value through an organisation is a significant challenge [30]. Simulations and animations provided such a mechanism for the case study firm. There are various ways to enhance simulations to make them more accessible. Turner and Garn [24] discuss aspects such as immersive simulations in virtual reality and optimisations, which may increase managers' acceptability. Data analytics provided the platform for TSEF to demonstrate its power to shift the focus of change from a narrow activity focus to a wider enterprise. Through developing simulations to demonstrate the benefits of an even flow of parcels between the process stages, the project team gained buy-in to implement the changes to the process within the operations hub and its linked distribution centres.

"Seeing what would happen to my job once the changes occurred made it easier to support it, though they still have to sort out the number of failures at the Operations Hub for it to work", stated one operator. The visualisations developed through modelling aided the project team in explaining the potential benefits to the organisation. Developing a mechanism that provides employees with the confidence to try new ideas in a safe environment is critical for long-term sustainability and lean improvements [21]. Experiments with the physical system would have affected the daily operations. Hence, simulations were decided to be used; this is supported by Kelton *et al.* ([50], p. 3). They explain that simulations are a particularly useful approach for modelling complex systems. Borshchev and Grigoryev ([51], pp. 26–36) supports this view and identifies simulation as a requirement for companies in their decision-making process. Discrete event simulation lends itself naturally to be a TSEF tool since it is based on entities flowing through the system, characterising and defining variations caused in various process stages.

Understanding where variation comes from. The research identified that the variability that affects flow can be generated either externally or internally [11]. Customer-derived variability is an important activity in service-based organisations, and it can be addressed by smoothing the demand entering the process [49]. This option, however, was not available to the case study firm. On the other hand, reducing internally generated variance was possible. Our findings illustrate that the major gain for the business was achieved through evenness of flow. Removing the in-built stoppages to smooth flow inherent in the design of the process delivered the improvements sought. Smooth flow, not efficiency of machinery or labour, was the key to unlocking the improvements and subsequent cost savings for the organisation. "We always focus on improving the process as it is. Changing the design of the process is not something that we had considered", remarked the quality manager, reinforcing Skinner's point that changes in process design are "powerful engines" for improvement.

Theoretical contributions and managerial insights. TSEF has been deployed by many researchers to explain the underpinning rationale of productivity and performance improvements [10, 11, 52]. However, empirical evidence to support process variability and throughput times factors as key measures in deploying TSEF has been limited. This research contributes to the literature by validating the two factors as pivotal in delivering process-based improvements. Through the development of a novel DES application, the case study identified and overcame several obstacles to TSEF implementation.

The derived DES approach in this study is reproducible and demonstrates its utility with production improvement frameworks. Combining DES and the TSEF concept highlights the value of simulations in assisting researchers in examining process improvement issues. The lack of sustainability in continuous improvement techniques such as lean is frequently reported [6, 17, 18]. The approach revealed in this paper highlights the opportunity for future studies to utilise simulations as a lens to examine why improvements become stymied.

Managerially, our study reveals several inhibitors to reducing variation and throughput time improvements. Silo structures and a lack of vision at an enterprise level were shown to limit progress and ambition. Inappropriate performance measures were found to focus on labour and machine efficiencies rather than reducing process variations, therefore improving business levels. TSEF, through the facilitation of DES, encouraged operations managers to venture out beyond their realm of responsibility. Through applying DES, managers quantified and validated the feasibility of change implementations beyond individual silos. DES revealed the importance of managing variability effectively, providing assurance that envisaged changes were worth pursuing. The improvements not only helped the operation hub save costs but, more importantly, assisted the distribution centres and the entire business in achieving substantial cost savings. This enabled the case study company to become more competitive.

Limitations. Our findings are derived from a single in-depth case study on the application of TSEF in a mass service environment with synchronised activities. This limits the generalizability of the findings but has allowed the researchers to develop insights that can be examined in the wider contexts of services. It is worth noting, however, that the approach has allowed the organisation to develop a roll-out plan for other sites, highlighting its transferability.

Schmenner *et al.* ([52], p. 339) state that the purpose of theories is to "make predictions" of how phenomena work and that the theory can be "disproved by findings that run counter to their predictions or explanations". Our findings have supported the "prediction" of TSEF. However, our research was based on a single case study of a high-volume business that had started to address some of the issues that affect the flow between the two sites. Further research is required to test TSEF in service environments that have different process variety and volume characteristics. Research is needed to examine the deployment of TSEF in environments where the customer is co-creating the service, which challenges the standardisation of processes, increases variability, and drives serial activities. As TSEF argues, "productivity rises with the speed of flow of materials through a process and reduces with increases in the variability associated with the flow" ([16], p. 102). Examining the application of the theory in an agile environment would be a further test of its explanatory power.

8. Conclusion

Three key questions were posed in conducting the investigation: (a) Can TSEF breakthrough where lean principles become stymied?, (b) What is the role of DES in discovering process inefficiencies, validating the feasibility of change implementations, and saving costs? and (c) Does DES support TSEF as a business-level improvement tool? The historical improvement approach utilised by the case study company had stagnated at a low level of lean maturity [33]. Lean principles delivered isolated efficiency-based improvements and sub-optimisation across the company-wide processes. The study demonstrated that DES lends itself naturally as a tool for the TSEF. This allowed the case study firm to enhance its vision for the process, develop focused factories, and substantially reduce costs. Our research has found that TSEF, in combination with DES, offers service organisations a practical option to improve performance.

Our findings from the case study have allowed us to elaborate on TSEF and how it can stimulate more strategic solutions for productivity (*e.g.*, focused factories). Our research has highlighted several mechanisms that are important for the implementation of TSEF, moving the concept from the academic design board to the practitioner's toolbox. Both strategic and operational elements were found to be important if the potential of swift, even flow is to be realised. The design of the company-wide processes that deliver value and the missions given to different operations may lead to variation that should be managed. Removing or reducing self-induced variation requires a strategic review of the structure of the system (*e.g.*, the character of the focused factories established), which is in addition to the acknowledged variations of the process itself.

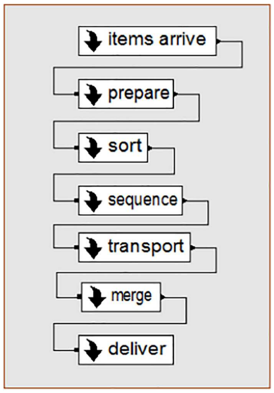


FIGURE A.1. Process stages.

APPENDIX A. DISCRETE EVENT SIMULATION IMPLEMENTATION

The as-is and to-be scenarios were implemented using Rockwell's Input Analyzer and Discrete Event Simulator (DES) Arena. The simulation models can be found on Github [53].

Most of the probability distributions mentioned (Tab. 2) were derived using an "Input Analyzer". This tool fits several standard distributions to fit the given data. The one with the least mean squared error is ranked top. Visual verification and consideration of the Kolmogorov-Smirnov test and the Chi-square test (especially the p-values) eventually led to the decision about the probability distribution to use to describe the service times.

The structure of the as-is process was mapped in the DES. The high-level mapped process is shown in Figure A.1.

The modelling of the truck arrivals is shown in Figure A.2. Trucks arrive at the operations centre at 4 am, as described in the main text. The truckloads are split into entities (1 entity = 100 parcels). After 24 h of incoming parcels, the cut-off time for the days arrives, *i.e.* all further parcels are discarded. At the cut-off time (28 h), the volume of the day is known. Figure A.2 also shows several sub-systems running concurrently. One of them checks that the timings are logically correct (at bottom Fig. A.2). Another one ensures that the volume will be set, even if trucks stop arriving. The third one ensures that the volume for the first batch is set appropriately.

After the truck's arrival. The parcels are unloaded and prepared (Fig. A.3). At this stage, we need to decide whether parcels are classified for batch (wave) 1 or 2. This is achieved by knowing the starting time of the batch 2 cycle. The logic systems monitor the start and end time of the preparation process.

Following the preparation, the sorting stage starts. Figure A.4 shows the modelled implementation. Initially, the items are held in a storage area until sorting can start (specified by the sorting start time). Note that once sorting has started, parcels can pass through the storage directly. However, if the parcels are meant to be processed as the second batch (wave 2), they will be kept in the storage area. The required sorting time for each parcel is recorded. The actual sorting process uses several (in this case, five) machines. The service time of each machine varies according to a gamma distribution. We also record the number of items and other sorting measures, such as the current throughput performance. In parallel, we run the KPI sub-system (Fig. A.5), which records essential key performance indicators. These include the number of items processed for each of the two batches, the throughput rate for the system, the throughput rate per machine, and the throughput time.

Figure A.7 shows the transportation model. The two batches are dealt with separately. The transportation process utilises the whole fleet to transport the parcels to the distribution centres. Note that the reverse transportation times are neglected.

After the sorting stage, the sequencing stage begins. The implementation is displayed in Figure A.6. The storage for the sequencing is emptied for batch 1 at 10 pm. Batch 2 needs special attention because the

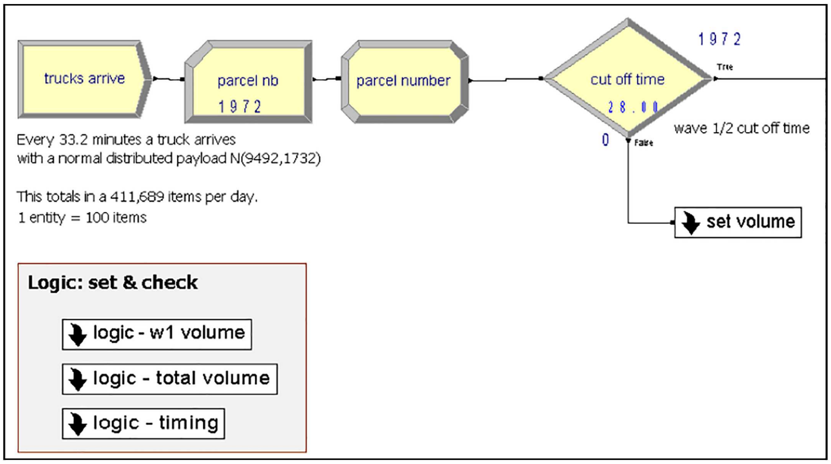


FIGURE A.2. Arrival process.

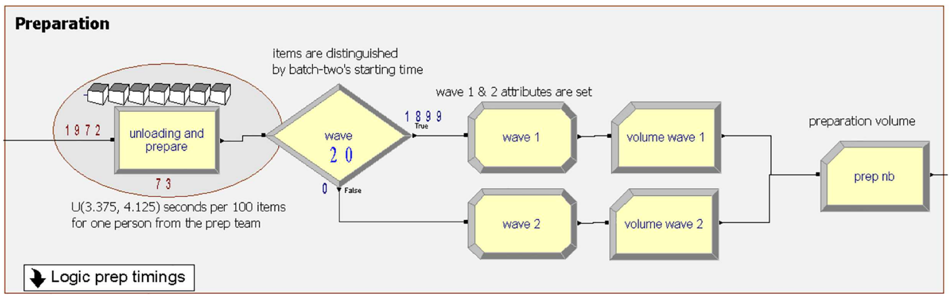


FIGURE A.3. Unloading and preparation of parcels.

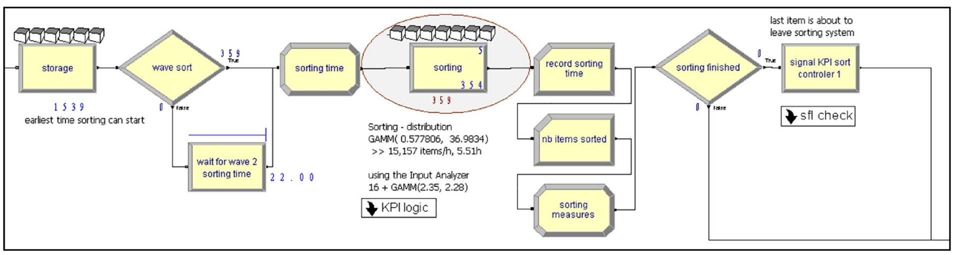


FIGURE A.4. Sorting stage.

sequencing of this batch may not start before the other one has finished. The sequencing itself is split into the labour and machine parts to reflect reality more accurately. The KPI logic system works similarly to the one explained in the sorting stage. At the structural end of this process stage, the transportation process stage is signalled (informed) about the status of each batch process.

After the parcels have been delivered to the sorting centre, they are merged, as shown in Figure A.8.

After the merging process, parcels are ready for delivery. A simulation run stops as soon as the last parcel has been merged. Simulation runs are replicated a hundred times to ensure statistical stability.

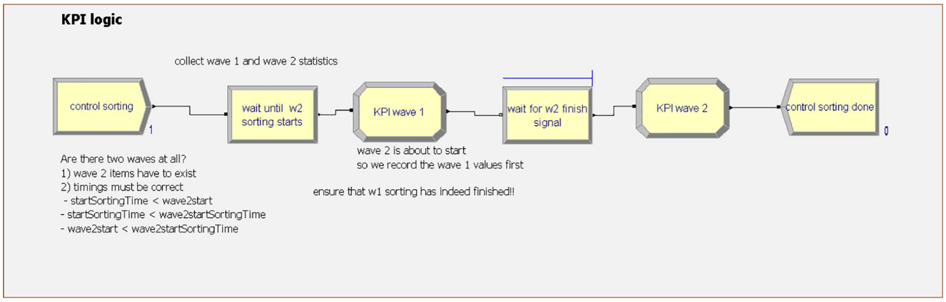


Figure A.5. KPI logic for the sorting system.

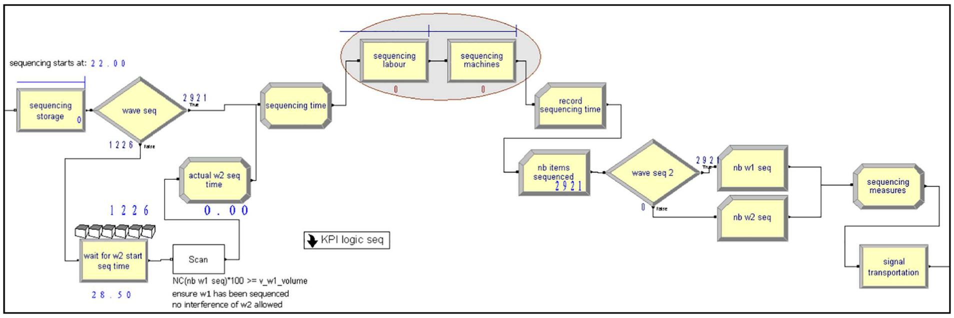


Figure A.6. Sequencing stage.

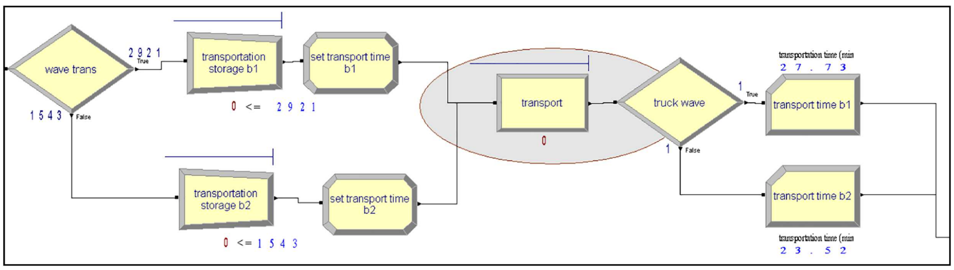


Figure A.7. Transportation model.

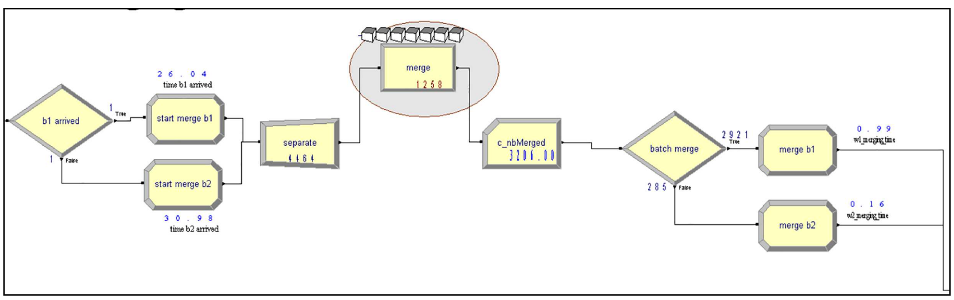


Figure A.8. Merge process implementation.

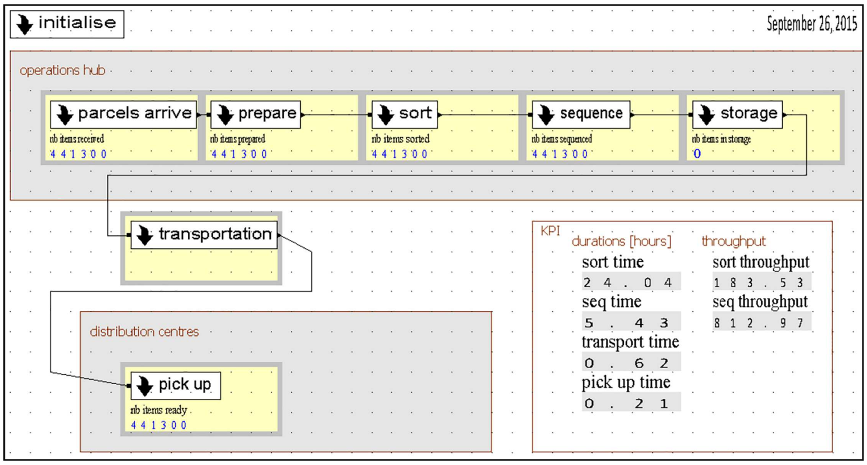


FIGURE A.9. Implementation of to-be scenario.

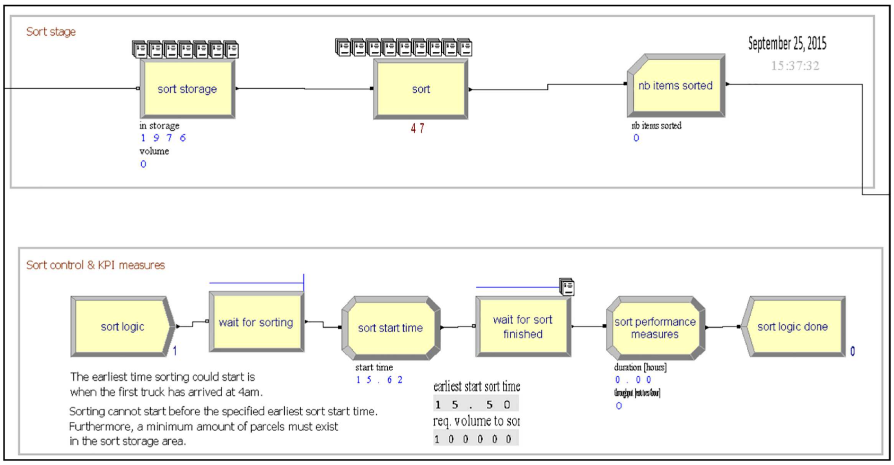


FIGURE A.10. Sequence stage of to-be scenario.

The to-be scenario is displayed in Figure A.9. It reflects all the essential stages, implemented as sub-systems. In general, the implementation is similar to the as-is scenario with the simplification that it is not necessary to distinguish the two batch cycle processes.

Thus, we will only display the sorting stage (Fig. A.9) and sequence stage (Fig. A.10). Theoretically, the earliest time the sorting could start is when the first truck arrives at 4 am. The sorting control logic requires that sorting cannot start before a specified time. Further, a minimum number of parcels must exist in the storage area. This allows more efficient processing. From the as-is scenario, an "average" lower bound for the earliest sorting time can be derived through reverse engineering. We know that pick-up (former merging) will take less than 1.53 h, transportation will take less than 0.96 h, sequencing will take less than 5.71 h, and sorting will take less than 11.12 h. This sums up to 19.32 h, and the planned delivery start time is 9 am. That means the earliest start time for sorting can be set to 13.68 pm. Taking into consideration the shortened merging (pick-up) stage (average: 0.19 h, max: 0.25 h) and the shortened transportation time (average: 0.48 h, max: 0.66 h), a reduction of 1.82 h is possible. That leads to a refined start time of 3.50 pm. A more precise start time can be obtained by either using an experimental design or running an optimisation.

Further, the merging process is not necessary and is substituted with a pickup process. The delivery staff can do this in a far shorter time. This time is normally distributed with a mean of 1.25 min and a standard deviation of 0.626 min for 100 parcels per person.

Data Availability Statement

The simulation models created for this paper are available online in a Github repository: https://github.com/Wolfgang-Garn/pass-the-parcel [53].

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