# The digital twin model of vehicle containers to provide an ergonomic handling mechanism

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## Abstract

Late order loss for difficulty handling (loading and unloading) activities left an alarm message to make traditional transportation handling for distribution e-commerce more accessible through mitigating it to semi-auto actions. This article discusses the idea of Vehicle Containers made up of Permutational Drawers, i.e., VCPD, that ensure ergonomic handling. The proposed Ergonomic Digital Twin (EDT) manages the VCPD by the Internet of things, i.e., IoT. The VCPD object has two dimensions: drawers' size and motion mechanism. These targets are implemented via establishing the digital twins' model, i.e., DT, for these drawers to test its qualifying for implementation, mainly if supported by IoT. There is still much confusion regarding the DT and how it will apply to the VCPD in medium-sized schemes for transportation enterprises. This work activates the IoT to bolster and simplify transportation activities through designing VCPD and control via a unified framework having several standard steps to reduce execution time, effort, and transportation costs.

## Keywords
Digital twin, IoT, Ergonomic Design, Mechanism design, and Container Repositioning.

## 1. Introduction, Digital Twins in transportation

The article hopes that digitalizing all transportation activities via the smart sensors platforms enhances the M2M interaction relationship. Digitalization must be aided by several recent technologies such as the Industrial Internet of Things (IoT), artificial intelligence (AI), machine learning, and cloud computing (Ahmed M. Abed, 2020). Many researchers unanimously agree that a digital twin, an electronic replica of an organism, machine, parts thereof, or service (e.g., transportation is a service based on the organism) has four vertices (stakeholders, product, mechanism,

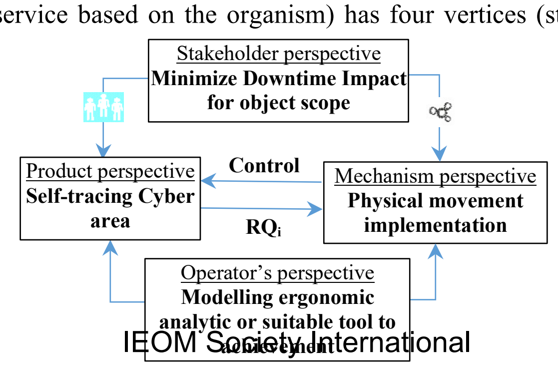





Figure 1. The bypass in bi-direction

and operators), with keep that the actual object/product (i.e., drawers) is connected to its virtual electronic version in an exceedingly way that permits data to be transferred between both mutually periodically (i.e., to modify the design (e.g., size, the weight of contents, empty spaces) according to stowage map, which interested with returned products). In line with a recent Gartner and researchers poll., 2019, which revealed 75% of enterprises are using IoT via designing digital twins to manage overall activities within the subsequent year. Over two-thirds of those businesses are expected to own a minimum of one digital twin aspect in their outputs by 2022 (Gartner, 2019), which can address by digitizing their operations, service mentality, and marketing acceleration. The digital twins were defined initially in 2002 (Grieves and Vickers, 2016) as "Digital info-media construction of a physical system as a single entity." began from a basic conceptual model of the product (i.e., drawer) life cycle management (PLM) to the term 'twin,' which refers to the fact that will link these digital data to the physical while incomplete existence, this think may enhance the closed stakeholders' chain cycle. Using this approach in transportation, which pushes the operators to develop workable digitization of all entities in their transportation schemes (e.g., from source to destination), via with analysis, decision-making, and control in agreeing to rules as illustrated in Figure-1, that means interactive bypass in two directions as illustrates in Figure-1.

The purpose of this study is to integrate these paradigms on the digital twin to derive a unified structure (i.e., domain) that allows industrialists to construct their digital twins to achieve specific goals readily through achieving five requirements as shown in Figure-2, inexpensively, and fast as has been deduced a standard and technology roadmap (Hedberg T Jr., Helu M, Sprock T., 2018), also tackling the Product lifecycle management (Grieves M., 2005) who put the basics of digital twins' concept and implementation. The Digital twin does well in facilitating corrective acts and predicts faults/fatigue even before they occur (i.e., over-processing/ergonomic issues). This interactive relation of EDT allows any physical object to interact with each other and with humans to enhance this relationship. The EDT is the true incarnation of implementing the Internet of Things, i.e., EDT=> VCPD & IoT, as pointed to Ahmed M. Abed, 2016, and Haag, S. and Anderl, R., 2018, who designed their framework mutually allows data flow is bidirectional.

### 1.1 Objectives

The main objective of the research is to define a simple guide to activate the digital twin in industrial operations and study their effectiveness. Also, it proposes some acceleration steps in transportation activities (i.e., vehicle routing consuming time) to create an ergonomic system that leads to customers satisfaction who get the goods early.

## 2. The Digital Twin establishing

Some researchers have recognized that the real-time visualization of closed control schemes to need decisions is also a vital step with digital twins than a disjointed virtual replica of a physical system such as illustrated in Figure-2, which consider the digital twin structure via meet the five requirements demonstrated in Figure-2. Table-1 discusses the Figure-2 elements and shows its definitions, relevant target standpoints (i.e., physical object, products, process, or service), the fidelity of digital acting (i.e., completed, or partial exemplification), and chronological interdependence (e.g., on or offline) (DUBLIN, 2020). Alternatively, an offline digital twin would attach to a commonplace's physical system. The difference between an offline digital twin and an emulation model is the periodic link, as discussed by (GE., 2018).

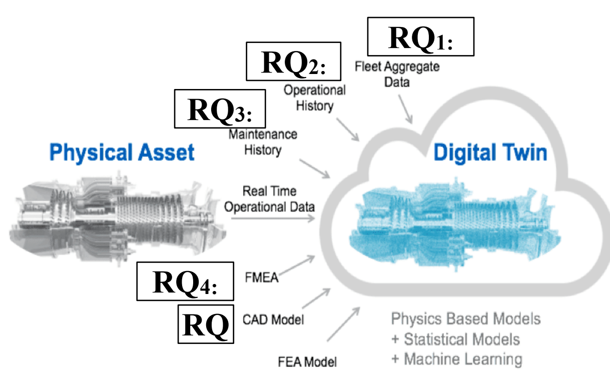



Figure 2. Source: (DUBLIN, 2020), Illustrative digital twin example

Table 1. $RQ_i$; A Compilation of Different Standpoints on the Ergonomics' Digital Twin (EDT)

| Reference | $RQ_1$, Familiarization | $RQ_1$, Fleet aggregate data | $RQ_{2\ \&3}$, Standpoint | $RQ_4$, Fidelity | $RQ_5$, CAD model |
|---|---|---|---|---|---|
| GE. 2018 | Software representation | Offline | Product, Process | Completed | Yes |
| Siemens (2018) and also, Ahmed M. Abed (2020) | Virtual counterpart or computerized | On/Off-line | Product, Process, and Service | Completed | Yes |
| Siboni (2020) | Fully completed model | Online | Process, service | Piecemeal | None |
| Tao and Zhang (2017) | Authority model | Offline | Product | Completed | Yes |
| Coronado et al. (2019) | Digitized model | Offline | Service | Completed | Yes |
| Ahuett-Garza, (2018) | web-based system | Online | Service | Piecemeal | None |
| Bao, J., et al. (2019), Kritzinger et al., (2018) | Cyber counterpart or computerized | Online | Service | Piecemeal | None |
| Ahmed M. Abed et al., (2020) | Data and model | Online | Process | Completed | Yes |
| Boschert and Rosen (2016) | manifestos and paradigm | On/Off-line | Product, Process, Service | Piecemeal | None |
| Islam et al. (2020) | Digitized representation | Offline | Product | Completed | Yes |

By extrapolating from Table 1, a digital twin shouldn't collect all accessible data from the real world, but only the knowledge relevant to the particular use case (i.e., vehicle's container accessing). Likewise, there should not be one digital twin for a physical paradigm. Still, a spread of DTs that support their intended serves to avoid the high expenditure (Berti, J.G., 2019). At the same time, the purpose of the standpoint model is assumed to be system (i.e., manipulation service). The study defines the system as digitizing, cyber, or computerized counterpart (Eckhart, M. et al., 2019).

Moreover, the study determines the degree of fidelity (completed) and the indicator of temporal integration in real-time or offline as discussed and reviewed (Grieves M. et al., 2016). The analysis concluded by developing the approach of Bolton D. 2016. Siemens et al., 2018 and updating Ahmed. M. Abed et al., 2020.

## 3. The proposed EDT framework entities

The EDT integrates the VCPD and IoT through three main criteria modify the outlines of the needed framework, which may influence the breadth and limits of a digital twin model:

**3.1. $RQ_1$, [DTA] Fleet aggregate data:** The digital twin's models require online or offline updating according to service requirements during the time frame. The performance of EDT measures saves service time and likewise reduces the danger of fatigue. Additionally, the fidelity in supporting the transportation activities such as unloading or receiving returned items to placing them in the empty spaces. Therefore, should determine:

**3.1.1. Familiarization of the expected goals:** To determine the hopeful design (drawers' dimension and motion mechanism), the authors wish to define the design requirements precisely through step-by-step pictorial monitoring for actual operational activities. Generate this design needs digital sensors for aggregating data about the products weights, volumetric dimensions, empty spaces, which has turn access on by many trips at various destinations. This design is managed through IoT via “RQ1, fleet aggregate data.” and requires familiarization with the appropriate hardware's need next.

*3.1.1.1. The device connectivity and data format* cover how sensors and actuators communicate with legacy devices in EDT, the raw format of datasets created by machines, how devices communicate with the edge layer (e.g., PLCs and RTUs) in local EDT. While, activate the protocol translation between devices and gateway using the telemetry schemes based on BAC-net and Modbus such as eco-design Bluetooth, Z-Wave, ZigBee, Wi-Fi, Ethernet, and Serial Port, to feed the sensors to meet **$RQ_1$**.

*3.1.1.2. Identify the PACE's sensors*; It must meticulously identify hardware, equipment, and machinery to urge appropriate suitable sensors needed to link them to the designed platform, counting on the organization goals and desired outcomes through the period of "operational history" to meet **$RQ_2$**.

**3.2. $RQ_3$, [DTI] Standpoint:** The standpoint determines whether development is needed via studying "the maintenance capability/reliability of operation history." Then selects suitable mechanism wanted, such as if the digitizing twin will mimic the historical behavior of the paradigm (i.e., emulation) or if it will establish a dynamic model express the paradigm, i.e., simulation, (Brooks B. et al., 2014). Therefore, we should prepare the data points and metrics.

**3.2.1.** Preparation of data points and benchmarks consistent with results is a good step generated by the sensors attached to the cloud devices, resulting in enormous datasets. Therefore, it's critical to pick or guide the appropriate data points to contribute to the metrics. These points define the connectivity tactic that should be designated the device connectivity (**$RQ_1$** and **$RQ_3$**).

**3.2.2.** The setting needed to support a standpoint determines how data is saved before transferring to the IoT platform. Also, ensure the edge layer that must convert the transfer protocol to wireless protocols to provide the digital twin (e.g., CSV to XML to JSON).

**3.2.3.** Identify authority datasets required for transforming sensor data; when the correct setting is provided to the datasets collected by sensors and devices, they become relevant.

**3.3. $RQ_{3.1.}$, Accessibility**, is crucial for the Digital twins' model, which is supported with IoT, as a Clouds computing initiative via the platform as well discussed in Table-2 later, which must be carefully anonymized, encrypted, and compressed to transfer acceleration through intelligence dashboards as discussed in bullets 1, and 2 of this section.

**3.3.1. Identify hot path analytics for near-real-time treatment;**

single data points (i.e., traditional EDT) must be reviewed as they are generated, as aforementioned. After detecting unexpected indicators of arguments restrictions, the IoT platform may be too late to take a suitable decision.

The digital twins' platforms illustrate in Table-2 a set of components that help prepare and manage Internet-related devices in real-time. One person, DTA, can collect data remotely from the system DTIs, control, and manage all Internet-related devices DTP, as noted by Grieves, M., 2014. The study prefers to use a platform that supports device managers and adopts any data collection methods convention. The target for analysis indicator should be done in real-time and supports a visualization policy, as noted by Berti, J.G. and Deluca, LS, 2019. Therefore, the study selects the Kaa IoT platform to digitize the traditional EDT to create an EDT framework (Table 2).

Table 2. Comparison for open-source Internet platforms

| IoT software platform | Do sets manage? | Strengthened | Basic Authentication | Data aggregation charter | Assay | Visualization support? | DataBase |
|---|---|---|---|---|---|---|---|
| Kaa IoT Platform | Yes | Mobile SDK is available to integrate any given platform, REST API | Link Encryption (SSL), RSA key 4096 bits, AES key 512 bits | MQTT, CoAP, XMPP, TCP, HTTP | Analyze and visualize IoT bi-data in-time Kaa Apache, Cassandra-Apache, Zappelin | Aye | MongoDB, Cassandra, Hadoop, Oracle NoSQL |
| DeviceHive | *Unknown | REST-AP, MQTT APIs | Basic Authentication using JSON Web Tokens (JWT) | REST API, WebSockets, or MQTT | Online analytics (Apache Spark) | Aye | PostgreSQL, SAP Hana DB |
| Thingsboard.io | Yes | REST APIs | Basic | MQTT, CoAP, | Real-time | No | Cassandra |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | Authentication | and HTTP | analytics (Apache Spark, Kafka) | | |
| WSo2 | Yes | REST APIs | Link Encryption (SSL) and basic Authentication | HTTP, WSO2 ESB, MQTT | Yes, WSO2 Datum Analytics Server | Aye | Oracle, PostgreSQL, MySQL, or MS SQL |

### 3.2.2 Define paths for batch processing

The framework classifies the sensors' data collection into two types, hot, i.e., indicators must be collected now, and cold, i.e., may be processed later, which is considered an essential part of developing an IoT solution as Grieves, M. and Vickers, J., 2017. This article adopts Kaa IoT to support the visualization in real-time through the open database.

## 3.4. $RQ_4$, [DTP] The Expected Benefits of EDT framework and its needs.

At all levels of transportation, a DT of stakeholders, products, processes, or service/regime can be employed in various ways (e.g., M/c, cell, line, annex-facilities, or supply-chain).

***a)*** ***Minimizing the impact of mechanism downtime:*** Therefore, the framework should be "self-tracing and repairing twin" via the monitor, troubleshoot, diagnose, and predict transportation equipment/devices faults and/or faults/fatigue to control the equipment. The preferred method in this setting is FMEA. The failure mode and effect analysis is based on the RPN risk priority number of multiply severity, occurrences/probability, and detection as shown in Table-3 and digitized as shown in Figure-3, and start the development from the maximum RPN. The '$\mathbf{RQ_{4.i}}$' is divided to process, system, service, and software FMEA, as shown in Figure 4.

Table 3. The part of FMEA to develop the twin behaviour

| Item / Function | Potential Failure Mode(s) | Potential Effect(s) of Failure | Sev | Potential Cause(s)/ Mechanism(s) of Failure | Prob | Current Design Controls | Det | RPN | Recommended Action(s) | Responsibility & Target Completion Date |
|---|---|---|---|---|---|---|---|---|---|---|
| Customer sends in a quote request for product. | System, Software, Integration and Shipping requirements overlooked by | Customer needs not fully met by delivered system. | 7 | Human error | 1 | Design configuration tool. | 3 | 21 | Use configuration tool when available. | Closed 10/31/21 |

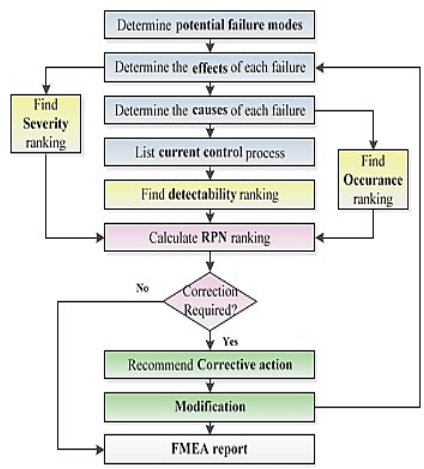



Figure 3. RQ4, FMEA Process to develop the object's twin

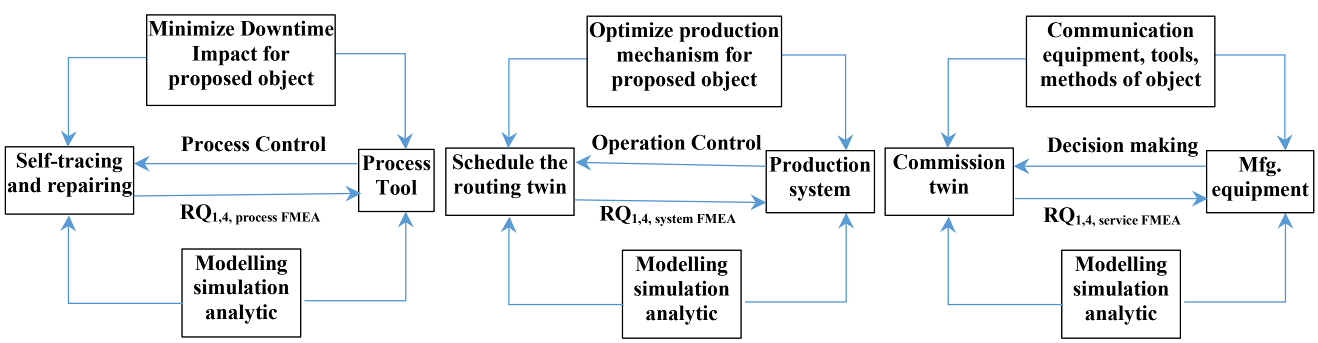


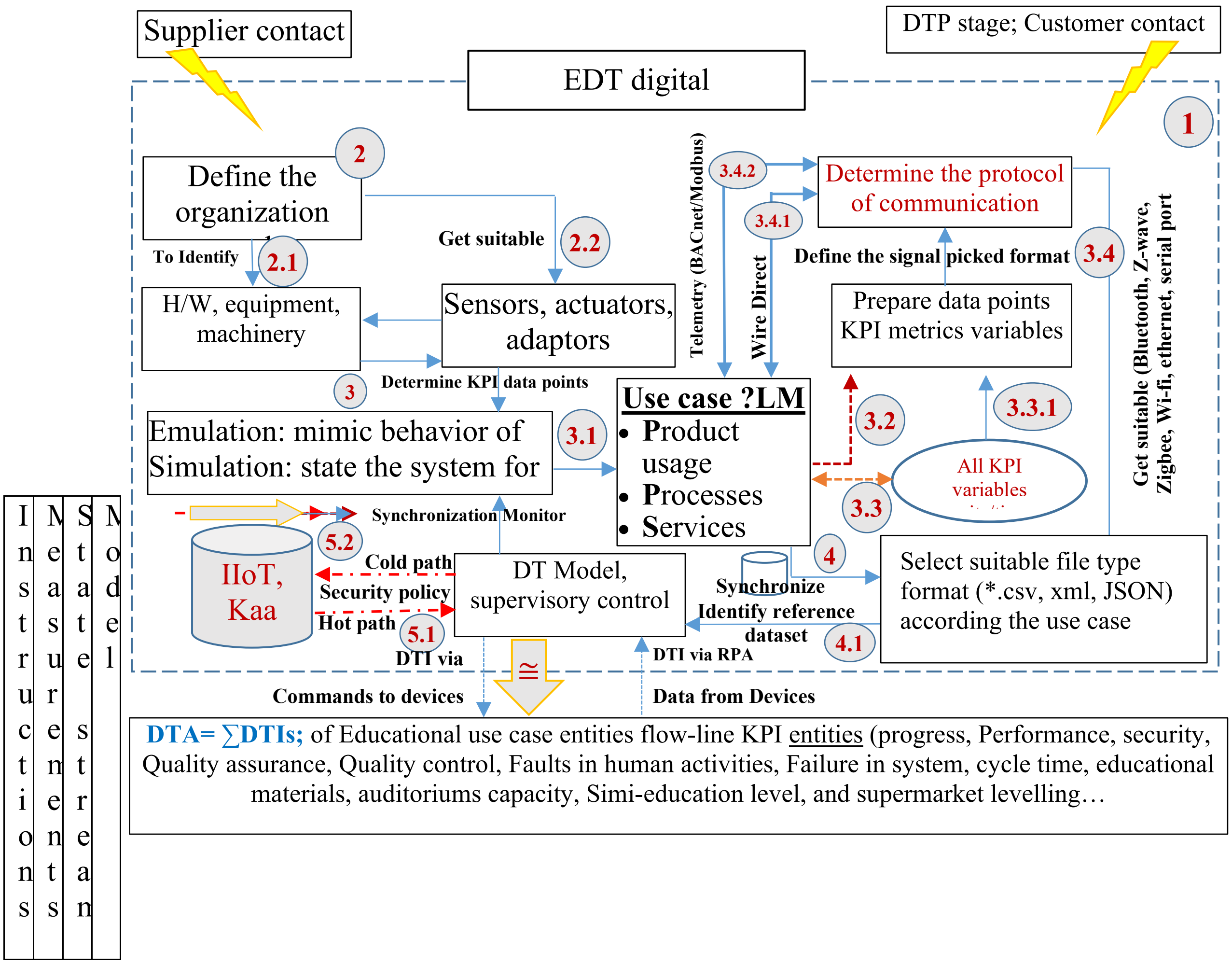

Figure 4. Depicts three cases of the use of DT in transportation sequence

## 4. The EDT domain structure

The EDT is a computer-controllable system that will recommend future work through transportation 4.0 approaches to minimize fatigue, as shown in Figure-4 of the core components of traditional EDTs—changed by replacing. It is shown. The DT integrates real protests' characteristics, conditions, and behavior using case models through information tracing. Haag, S., and Anderl, R. It are based intensively on the declaration by the partner by 2018. Figure-5 shows the coverage of the entire system along with the process and product lifecycle. Given the design, prototyping, test policy, training, and virtual versions of analog for this cycle, digitization can help eliminate difficulties by making precise assumptions, which will help achieve "self-reliant reform and repair." Ahmed M. Abed et al., 2020. In addition to talking about how the Digital Twin relates to Schemes Engineering and how it may help rectify "normal accidents" caused by human interactions as understand from Roberto. et al., 2022.

While Talkhestani, BA et al. (2018, 2019) and Coronado PDU et al., 2018 suggested integrating a PLM IT-Platform and a fulcrum (i.e., the data generated by multidisciplinary engineering tools) technique for detecting the mechatronic data structure discrepancies between digital models and physical schemes. Therefore, use automation software code to create a rule-based consistency checking and syncing the architecture models as noted by (Guodong, 2020). The proposed in the setting of transportation an approach of modeling and operational strategy. Firstly, the notion and expansion of the DT in the vehicle are detailed to give the implementation techniques of virtual-physical confluence and knowledge integration for a factory. Secondly, the modeling techniques for product, process, and operation digital twins are provided, followed by an explanation of the interoperation mode between these DTs. Thirdly, for modeling a structural parts machining cell, Automation Markup Language (Automation ML) is utilized to detail how to perform required activities, as shown in Figure-4. Finally, a performance evaluation illustrates how the suggested technique improves outputs efficiency. Therefore, Schleich, B., et al., 2017, and Zipper, H. and Diedrich, C., 2019 study proposes a strategy that uses optimization approaches to synchronize the states of the updating the model with those of the physical asset throughout outputs while also assisting in the detection and identification of changes. This stage is used to update a "double digital" version of the device's state in actual and real-time, called a "shadow device" used to develop the concept of a DT as cited by Ahmed M. Abed et al., 2020. The maestro of managing and updating the created twins is the IIoT dataset, which training some data at the cold path while synchronizing another influence data at a hot track to achieve fidelity situation, which the feedback and feed-forward flow across IIoT lifecycle phases (such as design and service) as shown in Figure-4, that contribute the vision 2030. At the same time, Eckhart, M., and Ekelhart, A., 2018, recreating CPS states based on properties only, needed for a wide range of security and safety measures.

The article presents an actual prototype implementation and assesses it in an experimental CPS test environment to demonstrate the viability of the specification-based state replication technique. The findings of Ekelhart, A., and the study indicate that attacks against CPSs may be successfully identified using the suggested state replication technique. The proposed ergonomic digital vehicle's container twin EDT developed the workplace as part of robotic process automation (RPA) as indicated in the proposed framework shown in Figure-5. The architecture of an EDT needs components enabling use cases like plug-and-play, self-x, and predictive corrective. Sundry procedures, including the Anchor-Point-Method, a method for diverse data gain and data unification, and an agent-based approach to progress a co-imitation (i.e., simulation) between EDT entities. The proposed framework respects the stages of modeling EDT twins (i.e., DTP, DTI, and DTA). The DTP considers designs, analyses, and processes paths to realize competitive transportation activities. Whereas a DTI is the digital access purpose of each equivalent of stakeholders, through its serial transportation processes'. While, the DTA could be a compilation of DTIs whose information and knowledge will be used to question academic progress, predictions, and learning. DTs' specific information is derived according to use cases (Gottfried Hastermann, 2021). With increasing numbers within the transportation processes, the opportunities for higher productivity are gap up. Therefore, the framework of the long-run industrialization results in four aspects: stereotyping, independence, communication, and digital schemes twin. The framework perceives a new method to optimize customer level, lessen variances, and assist with root-motive analysis. Finally, connectivity, just like the Internet, makes it feasible to narrow the gap of the digitization loop via the aid of online use. The proposed framework aims at increasing customer satisfaction, especially when monitoring, diagnosing, and predicting them, to improve asset performance and use based on DUBLIN, 2020 vision. In this setting, sensory data can be combined with significant data, human and fleet experience, and simulation learning to improve the results of predictions as recommended at ASME 2021 [36]. Therefore, complex forecasting platforms and an innovative corrective system can use DTs to find the underlying cause of problems and enhance outputs as recommended by Alberto, 2022. This stage preludes predictive corrective for its ability to forecast and identify variances for individual equipment or transportation processes that indicate the need for preventative repairs or corrective before a serious problem occurs.


Supplier contact
EDT digital
DTP stage; Customer contact
1
Define the organization
2
To Identify
2.1
Get suitable
2.2
H/W, equipment, machinery
Sensors, actuators, adaptors
3
Determine KPI data points
Emulation: mimic behavior of
Simulation: state the system for
3.1
Telemetry (BACnet/Modbus)
Wire Direct
3.4.2
3.4.1
Determine the protocol of communication
Define the signal picked format
3.4
Prepare data points KPI metrics variables
Use case ?LM
Product usage
Processes
Services
3.2
3.3.1
All KPI variables
3.3
Get suitable (Bluetooth, Z-wave, Zigbee, Wi-fi, ethernet, serial port
Synchronization
Monitor
5.2
IIoT, Kaa
Cold path
Security policy
Hot path
5.1
DTI via
DT Model, supervisory control
4
Synchronize
Identify reference dataset
4.1
DTI via RPA
Select suitable file type format (*.csv, xml, JSON) according the use case
≅
Commands to devices
Data from Devices
DTA= ∑DTIs; of Educational use case entities flow-line KPI entities (progress, Performance, security, Quality assurance, Quality control, Faults in human activities, Failure in system, cycle time, educational materials, auditoriums capacity, Simi-education level, and supermarket levelling…
Instructions
Measurements
State stream
Model

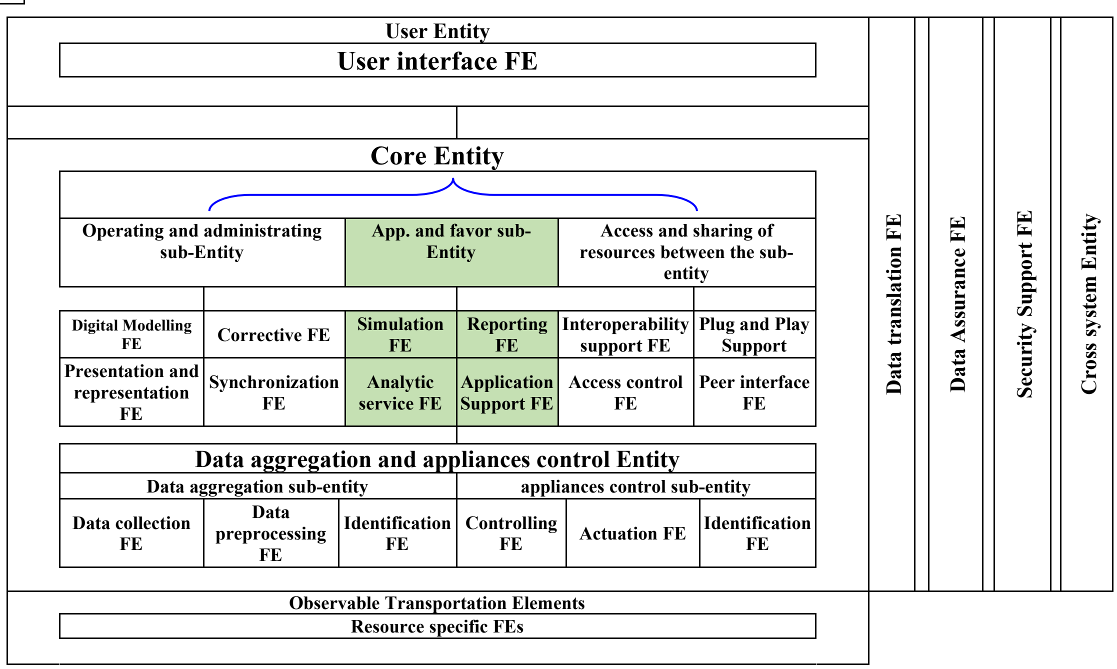

User Entity
User interface FE
Core Entity
Operating and administrating sub-Entity
App. and favor sub-Entity
Access and sharing of resources between the sub-entity
Digital Modelling FE
Corrective FE
Simulation FE
Reporting FE
Interoperability support FE
Plug and Play Support
Presentation and representation FE
Synchronization FE
Analytic service FE
Application Support FE
Access control FE
Peer interface FE
Data aggregation and appliances control Entity
Data aggregation sub-entity
appliances control sub-entity
Data collection FE
Data preprocessing FE
Identification FE
Controlling FE
Actuation FE
Identification FE
Observable Transportation Elements
Resource specific FEs
Data translation FE
Data Assurance FE
Security Support FE
Cross system Entity

Figure 5. The EDT framework to manage digitized vehicle containers.

## 5. RQ5, The EDT physical object design, and (VCPD ) mechanism

The permutational vehicle containers drawers help reduce workers' fatigue at loading and unloading transportation activities (West TD, 2017). The design of drawers' capacity according to average orders and demands for a specific firm, while and motion mechanism is the same. The virtual and real design has been developed via the EDT framework and tried at a famous Egyptian company. Figure-6 shows the pattern of drawers, and the dimension is an inherent right to every company's needs according to the following calculations discussed in section 5.1.1. This idea is inspired by the supermarket tool at VSM design that regulates the customer demand leveling during transportation stages. The DT was run on a Laptop with an Intel i5 processor with 8 GB of RAM. The real-world scenarios aggregated as shown in Table-4 to be tested to measure the efficiency of the twin's model to avoid the economic parameters and develop the CAD model (Shao G., 2018). (figure 6)

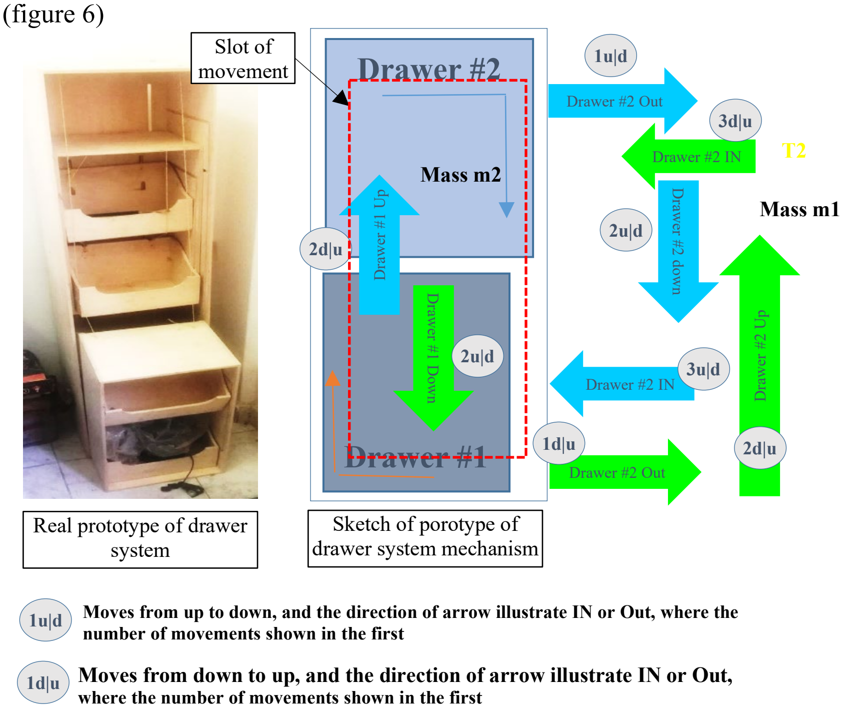



Figure 6. The proposed ergonomic vehicle's container drawers design

### 5.1. The digital model of the physical object

There is two-step of building the object's twin; the first is the economic drawer size according to use case, while the second calculates the suitable rope capable of loads movements up and down. The studied company (use case) will make its drawer!

**5.1.1. The first step**, the economic volumetric of the drawer, depends on the most loaded items of every company. The proposed model in **RQ5** considered a developmental model of Suzane Pedruzzi et al., 2016 and Lenz,O.U, 2020, via modifying some of the sets, parameters, and decision variables as follow in Table 3.

Table 3. Parameters, and decision variables

| | |
|---|---|
| **Sets:** | |
| P | : Set of packed items $\delta_i$, ranging from 1 to n, which $n \le Permissible\ weight\ limit = \sum_{i=1}^{P} \lambda_i$ |
| D | : Set of drawers $d_j$, ranging from 1 to m, which have a different volumetric capacity |
| C | : Clusters of Near similarity $\delta_i$ |
| **Parameters:** | |

| | |
|---|---|
| $n$ | : # of items to be transported, which is in the bypass or backtrack direction of the vehicle. |
| $m$ | : # of available drawers $d_j$. |
| $G$ | : A big number is used to balance the model logicality. |
| $g$ | : A small number used to balance the model logicality |
| Vr | : Volumetric occupied in a real system |
| Vm | : Volumetric output of the model implementation |
| $\nabla aa$ | : Available stowed area at creating twin, can assume as a percentage values among 0:1, where 0% stipulate not available space to stow or (i.e., the drawer is full) and grows this value gradually to 1 that guarantee 100% (i.e., the drawer is empty). |
| $l_s$ | : The loading sequence of $\delta_i$, where the item with the highest value (area of upper face, weight) stowed first, before lowest, i.e., $\delta_{i-bottom}$ have surface face area > $\delta_{i-above}$ |
| sa$_i$ ($cm^3$) | : surface area of $\delta_{sa_{i-b}} > \delta_{sa_{i-a}}$, where $\delta_{sa_{i-b}}$ refers to the surface area of item *i* in layer 0 or below, while $\delta_{sa_{i-a}}$ refers to the surface area of item *i* in layer 1 or above |
| $\lambda_i$ (kg) | : The weights of items $\delta_i$. |
| $l_a$ | : The layer of stowage, ranging from 1:*la*, where *la* is a layer of the durability of $\delta_{sa_{i-b}}$ at the bottom |
| $du_i$ | : The durability of $\delta_i$ to firmness another item above |
| $l_i, w_i, h_i$ | : The length, width, and height of $\delta_i$ |
| $L_j, W_j, H_j$ | : The length, width, and height of $d_j$ |
| $\varphi_i = \beta_j / \gamma_j$ | : The covering of each $m^3$ of drawer's $d_j$, i.e., the covering percentage of the total volume of the $d_j$ for the most famous $\delta_i$ loaded, while $\gamma_j$ is the volumetric capacity of the $d_j$. |
| $\omega$ | : Weight factor of the second parcel of a model, were ranging from 0.001 : 0.005 |
| **The decision variables:** | |
| $x_i, y_i, z_i$ | : Coordinates of lower left back corner of $\delta_i$ |
| $l'_{xi}, l'_{yi}, h'_{zi}$ | : Check if the length of $\delta_i$ is parallel to the X, Y, or Z-axis, $l'_{xi} = 1$ if the length of $\delta_i$ Parallel to the x-axis, while set 0 otherwise, also for other lengths. |
| $w'_{xi}, w'_{yi}, w'_{zi}$ | : Check if the width of $\delta_i$ is parallel to the X, Y, or Z-axis, $w'_{xi} = 1$ if the width of $\delta_i$ Parallel to the y-axis, while set 0 otherwise, also for other lengths. |
| $h'_{xi,} h'_{yi,} h'_{zi,}$ | : Check if the width of $\delta_i$ is parallel to the X, Y, or Z-axis, $h'_{xi} = 1$ if the height of $\delta_i$ Parallel to the z-axis, while set 0 otherwise, also for other lengths. |
| $a_{ij}$ | : Assignment of $\delta_i$ to $d_j$, where if $a_{ij} = 1$ refers to placing this item in drawer j, and set by 0 otherwise. |
| $d'_j$ | : Check if $d_j$ is used or not, where if $d_j = 1$ means it used and 0 otherwise. |
| $a'\Psi_{ikj}$ | : Check if $\delta_i$ and $\delta_k$ are placed in the $d_j$, where $a'\Psi_{ikj} = 0$ is assigned to $d_j$, while 1 otherwise. |
| $l_{ik}, r_{ik}, bh_{ik}, ah_{ik}, bl_{ik}, ab_{ik}$ | : Where relative position between two items, i.e., the variable $l_{ik} = 1$ if the $\delta_i$ is to left of $\delta_k$, with taking into account $i \neq k$, as same, other variables refer to $\delta_i$ is to right, behind, ahead, below, or above $\delta_k$. |

The digital twin of 'VCPD' is clarified in integrated three parcels identify the trial of optimizing the transportation capacity, as shown in Eq. (1), as discussed by (Siboni. S., 2020 and Piotr Pięta, 2021), which tailor the drawer dimensions according to the best fit of specific items.

$$V_m = \sum_{j\in D}^{C} \varphi_i (L_j, W_j, H_j n_j - \sum_{i\in P}^{C} l_i, w_i, h_i\, a_{ij}) + \omega(\sum_{i\in P} z_i + \sum_{i\in P} x_i + \sum_{i\in P} y_i) - \sum_{\delta_i=1}^{P} \lambda_i \ldots (1)$$

Although, the $d_j$ , dimension based on clustering the common stowage items (i.e., high demanded items) and studied into foursquare clusters side lengths of and cover the whole mesh of drawer with bins, counting the containers covering the area with ($\varphi$). As the size of each cluster varies, the total number of clusters changes as well; the theoretical drawer capacity is the ratio of covering logs ($\varphi$) divided by log (1/$\delta$) when $\delta$ is trending to 0, as illustrated in Eq. (2).

$$\varphi_i = \lim_{\delta\to 0} \frac{\log(\varphi)}{\log(\frac{1}{\delta})} \ldots (2)$$

In most cases, however, it is not possible to $\delta$ take the value of 0 directly. Furthermore, while altering the $\delta_{xi}$ of items, the proportion of $log_2(\varphi)$ to $log_2(\frac{1}{\delta})$ does not take on a fixed value but instead stays within a steady entr'actes, which are precisely described via the above parameters. Such, counting the changeable number ($\varphi$) of identical objects with different side lengths $l_i$ repeatedly and sketch versus ($\varphi$) on a log-log plot scale as shown in Figure-7, gives a linear relation using the least square method, while the utter value of its decline is the recommended $d_j$ size, which declares the amount of the self-identical proportion in statistics. Using the least-squares approach and a linear equation, the $d_j$ dimension is calculated according to the next precautions representative in Eqn. from (3) to (20) as deduced from (Luzie Helfmann, 2021). The number of $d_j$ can be computed by Eq. (3)

$$D_j = \frac{n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{n\sum_{i=1}^{n} x_i^2 - (\sum_{i=1}^{n} x_i)^2} \dots (3)$$

Whether the eqn. (4 and 5) interest in checking if two items $\delta_i$ and $\delta_k$ are inside the same drawer, while Eqn. (6-11) forbids overlapping situations at any side, below, or above.

$$2 - a_{ij} - a_{kj} \ge ga'\Psi_{ikj} \quad \forall_{i,k\in P}, j \in D \dots (4)$$

$$2 - a_{ij} - a_{kj} \ge Ga'\Psi_{ikj} \quad \forall_{i,k\in P}, j \in D \dots (5)$$

$$x_i + l_i l_{x_i} + w_i(l_{zi} - w_{yi} + h_{zi}) + h_i(1 - l_{xi} - l_{zi} + w_{yi} - h_{zi}) - a'\Psi_{ikj}G \le x_k + (1 - l_{ik})G \quad \forall_{i,k\in P}: i \ne k \dots (6)$$

$$x_k + l_k l_{x_k} + w_k(l_{zk} - w_{yk} + h_{zk}) + h_k(1 - l_{xk} - l_{zk} + w_{yk} - h_{zk}) - a'\Psi_{ikj}G \le x_i + (1 - r_{ik})G \quad \forall_{i,k\in P}: i \ne k \dots (7)$$

$$y_i + w_i w_{y_i} + l_i(1 - l_{xi} - l_{zi}) + h_i(l_{xi} + l_{zi} - w_{yi}) - a'\Psi_{ikj}G \le y_k + (1 - bh_{ik})G \quad \forall_{i,k\in P}: i \ne k \dots (8)$$

$$y_k + w_k w_{y_k} + l_k(1 - l_{xk} - l_{zk}) + h_k(l_{xk} + l_{zk} - w_{yk}) - a'\Psi_{ikj}G \le y_i + (1 - ah_{ik})G \quad \forall_{i,k\in P}: i \ne k \dots (9)$$

$$z_i + h_i h_{z_i} + w_i(1 - l_{zi} - h_{zi}) + l_i l_{zi} - a'\Psi_{ikj}G \le z_k + (1 - bl_{ik})G \quad \forall_{i,k\in P}: i \ne k \dots (10)$$

$$z_k + h_k h_{y_k} + w_k(1 - l_{zk} - h_{zk}) + l_k(l_{zk}) - a'\Psi_{ikj}G \le z_i + (1 - ab_{ik})G \quad \forall_{i,k\in P}: i \ne k \dots (11)$$

While designing the drawer $d_j$, face the feasibility of storage area are available or not to most demanded items (Kong, L., 2020). Therefore, the next eqn. (12-15) Guarantee the support area's existence so that the things are supported over each other safely. Variable $bl_{ik}$ is equal to 1 when $\delta_i$ is below $\delta_k$ and then precautions (12) to (15) are activated.

$$x_i + l_i l_{xi} + w_i(1 - l_{xi}) + (1 - bl_{ik})G \ge x_k \quad \forall i,k \in P: i \ne k \dots (12)$$

$$y_i + l_i l_{yi} + w_i(1 - l_{yi}) + (1 - bl_{ik})G \ge y_k \quad \forall i,k \in P: i \ne k \dots (13)$$

$$x_i + l_i l_{xi} + w_i(1 - l_{xi}) - x_k + (1 - bl_{ik})G \ge (l_k l_{xk} + w_k(1 - l_{xk})) \quad \forall i,k \in P: i \ne k \dots (14)$$

$$y_i + l_i l_{yi} + w_i(1 - l_{yi}) - y_k + (1 - bl_{ik})G \ge (l_k l_{yk} + w_k(1 - l_{yk})) \quad \forall i,k \in P: i \ne k \dots (15)$$

When the items $\delta_i$ and $\delta_k$ in the same $d_j$, then must check the relative positioning between them via precaution shown in Eq. (16)

$$l_{ik}, r_{ik}, bh_{ik}, ah_{ik}, bl_{ik}, ab_{ik} \ge 1 - a'\Psi_{ikj} \dots i,k \in P: i \ne k; j \in D \dots (16)$$

But, what about if the $\delta_i$ assigned to two different $d_j$. Therefore, the Eqn. (17, 18) formulated to prevent that.

$$\sum_{j\in D} a_{ij} = 1, \quad \forall i \in P \dots (17),$$

$$\sum_{i\in P} a_{ij} \le Gn_j, \forall j \in D \dots (18)$$

At this stage, design the drawers $d_j$ according to most demanded items $\delta_i$ and placed in a specific drawer, but must check from its fitting in this place by reducing the generated data (Iaroslav., 2021). Therefore, the Eqn. (19-22) interest

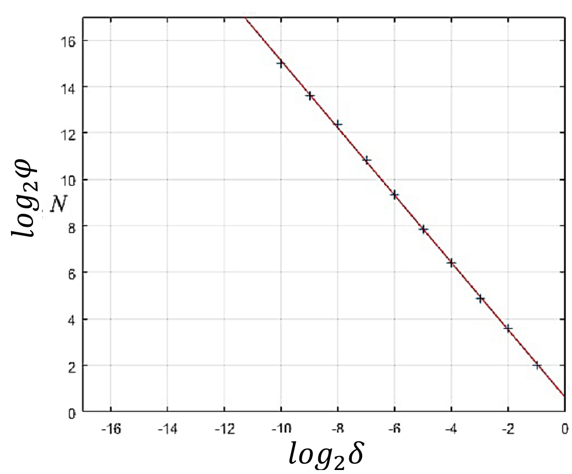



Figure 7. The linearly fit ramp with LSM, through eleven variant points of different $\varphi$ and $\delta$ are chosen for the studying use case company.

(Figure 7) in minimizing the wasted area in the physical dimensions of the drawer $d_j$, and ensure that the dimensions of every item $\delta_i(l_{xi}, w_{xi}, and\ h_{xi})$ must be parallel to one side of the drawer $d_j$

$x_i + l_i l_{xi} + w_i(l_{zi} - w_{yi} + h_{zi}) + h_i(1 - l_{xi} - l_{zi} + w_{yi} - h_{zi}) \le L_j + (1 - a_{ij})G\ \forall i \in P, j \in D, and\ l_{xi} + l_{yi} + l_{zi} = 1$ ... (19)

$y_i + w_i w_{yi} + l_i(1 - l_{xi} - l_{zi}) + h_i(l_{xi} + l_{zi} - w_{yi}) \le W_j + (1 - a_{ij})G \quad \forall i \in P, j \in D\ and\ w_{xi} + w_{yi} + w_{zi} = 1$ ... (20)

$z_i + h_i h_{yi} + w_i(1 - l_{zi} - h_{zi}) + l_i l_{zi} \le H_j + (1 - a_{ij})G \quad \forall i \in P, j \in D\ and\ h_{xi} + h_{yi} + h_{zi} = 1$ ... (21)

$l_{xi} + w_{xi} + h_{zi}\ and\ l_{yi} + w_{yi} + h_{yi}\ and\ l_{zi} + w_{zi} + h_{zi} = 1 \quad \forall i \in P$ .... (22)

The previous precautions of the proposed design guarantee placing all $\delta_i$ in specific $d_j$ and parallel to its side to assigned drawer at a specific position, with restricted reciprocal these items. Therefore, Eq. (23) allows reciprocal positions to meet the best fit and achieve maximum utilization via checking where:

$l_{ik} = r_{ik},\ bh_{ik} = ah_{ik},\ bl_{ik} = ab_{ik} \quad \forall i, k \in P: i \ne k$ ... (23)

The last precaution is to respect the durability $du_i$ of items $\delta_i$ in $l_{a1}$ to be more than in $l_{a2}$, and respect also the surface of the upper face as formulated in Eq. (24)

$\sum_{i=1\in l_a 1}^{n} {sa \times du_i}/{\lambda_i} \ge \sum_{i=1\in l_a 2}^{n} {sa \times du_i}/{\lambda_i} \quad \forall i \in d_j$ ... (24)

When implementing this model for specific clustered items can activate all precautions from (4) to (24) help in discovering the dimension of every drawer $d_j$ and get $l_i = 105\ cm, w_i = 0.92\ m, and\ h_i = 0.62\ cm$ . Therefore, $d_j$=**0.6*m*³** of different items respect Eq. (24) as a safe condition to transport the items safely. The box may have a square/rectangular base and a mesh bottom. Material costs of drawer $d_j$ = \$5.85 per $m^2$. The following section helps in deciding the most economical transportation capacity .

Table 4. Information from real-world scenarios

| | ***Demanded items*** | | | | | | | ***drawer*** | ***Calculations*** | | | | ***1 trip*** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **cluster** | **No. of trips/year** | **N: No. of orders in each cluster** | **Similar durability in a cluster** | **similar surface face in a cluster** | **Items dimensions *m*** $l_{xi}$ | $w_{xi}$ | $h_{xi}$ | **$V_r$: Volume $D_j$ $m^3$** | **No. of items picking < N** | **$V_m$: Volumetric capacity $m^3$** | **Not occupied spaces** | **Percentage of occupation** | **Cost losses of unused area \$** | **Trip time enhancement** | **Increased trips due to enhancing** |
| 1 | 35 | 25 | yes | no | 0.1 | 0.6 | 0.3 | 0.5 | 20 | 0.36 | 0.14 | 72.0% | 0.8 | 30.0% | 11 |
| | | 12 | ~~no~~ | ~~no~~ | 0.2 | 0.3 | 0.13 | 0.8 | 10 | ~~0.078~~ | 0.722 | 9.7% | 4.2 | 4.1% | 1 |
| | | 32 | no | yes | 0.18 | 0.23 | 0.35 | 0.5 | 30 | 0.435 | 0.066 | 86.9% | 0.4 | 36.2% | 13 |
| 2 | 12 | 20 | yes | yes | 0.15 | 0.31 | 0.13 | 0.5 | 20 | 0.121 | 0.379 | 24.2% | 2.2 | 10.1% | 1 |
| | | 20 | yes | yes | 0.18 | 0.23 | 0.23 | 0.5 | 20 | 0.391 | 0.31 | 38.1% | 1.8 | 15.9% | 2 |
| | | 25 | ~~no~~ | ~~no~~ | 0.18 | 0.23 | 0.35 | 0.8 | 20 | ~~0.290~~ | 0.511 | 36.2% | 3 | 15.1% | 2 |
| 3 | 20 | 8 | yes | yes | 0.1 | 0.3 | 0.3 | 0.5 | 8 | 0.072 | 0.428 | 14.4% | 2.5 | 6.0% | 1 |
| | | 33 | ~~no~~ | ~~no~~ | 0.2 | 0.3 | 0.3 | 0.85 | 30 | 0.44 | 0.31 | 63.5 % | -1.1 | *-ve* | 0 |
| | | 20 | yes | yes | 0.1 | 0.3 | 0.3 | 0.5 | 20 | 0.18 | 0.32 | 36.0% | 1.9 | 15.0% | 3 |
| 4 | 20 | 12 | no | yes | 0.15 | 0.3 | 0.35 | 0.40 | 10 | 0.158 | 0.243 | 39.4% | 1.4 | 16.4% | 3 |
| | | 10 | yes | yes | 0.1 | 0.3 | 0.3 | 0.5 | 10 | 0.090 | 0.41 | 18.0% | 2.4 | 7.5% | 2 |
| | | 34 | no | yes | 0.17 | 0.32 | 0.34 | 0.40 | 30 | 0.555 | Full | ------ | -0.9 | *-ve* | 0 |
| 5 | 25 | 19 | no | yes | 0.1 | 0.3 | 0.3 | 0.40 | 15 | 0.335 | 0.265 | 33.8% | 1.6 | 14.1% | 4 |
| | | 19 | ~~no~~ | ~~no~~ | 0.25 | 0.45 | 0.32 | 0.8 | 18 | 0.348 | 0.152 | 81.0% | 0.9 | 33.8% | 8 |
| | | 46 | ~~no~~ | yes | 0.15 | 0.3 | 0.38 | 0.8 | 40 | 0.684 | 0.116 | 85.5% | 0.7 | 35.6% | 9 |
| 6 | 17 | 10 | yes | yes | 0.18 | 0.3 | 0.38 | 0.5 | 10 | 0.205 | 0.295 | 41.0% | 1.7 | 17.1% | 3 |
| | | 21 | ~~no~~ | ~~no~~ | 0.18 | 0.33 | 0.35 | 0.85 | 20 | 0.216 | 0.034 | 92.4% | 0.2 | 38.5% | 7 |
| 7 | 12 | 21 | yes | no | 0.19 | 0.36 | 0.28 | 0.40 | 20 | 0.383 | 0.017 | 95.8% | 0.1 | 39.9% | 5 |
| | | 38 | no | yes | 0.12 | 0.3 | 0.23 | 0.40 | 30 | 0.348 | 0.152 | 62.1% | 0.9 | 25.9% | 3 |
| 8 | 35 | 59 | no | yes | 0.1 | 0.32 | 0.3 | 0.6 | 50 | 0.480 | 0.12 | 80.0% | 0.7 | 33.3% | 12 |
| | | 41 | yes | no | 0.1 | 0.32 | 0.3 | 0.6 | 40 | 0.384 | 0.216 | 64.0% | 1.3 | 26.7% | 9 |
| | | 33 | no | yes | 0.1 | 0.3 | 0.3 | 0.6 | 30 | 0.270 | 0.33 | 45.0% | 1.9 | 18.8% | 7 |

Table-4 shows the number of clustered orders to be stowed in the designed drawer as discussed in Eq. (1) to Eq. (3) and respects all precautions Eqn. (4 to 24), all negative values in occupation capacity replaced to full or loss 0%, and the reduction of costs approaching 8841 \$. The model presented a bad drawer design if the $\delta_i$ have different durability and upper face; otherwise, the model presents a volumetric with the minimum waste unused area. The enhancement appeared in the last column compensates by increasing the number of trips and the transported items. The Estimated annual gains (\$) ≅ 928346 as shown in Table-5.

#### *5.1.1.1. Draw a sketch RQ5!*

The particular case is to design the base as square, so we will just use.'$L_\rho$' for both lengths, the drawer has 4 sides with height $h_h$, and square mesh bottom. The drawer shape could be designed out like Figure-6, where Volume = $L_j \times L_j \times h_j = L_j^2 h_j$, and we are told that the volume should be $0.5m^3$: $L_j^2 h_j = 0.5$. The total area of all sides = $4 \times L_j \times h_j = 4L_j h_j$, while the Total Area $4\times L_j^2$ , then the Total material sides used = $4\times L_j \times h_j + 4 \times L_j^2$.

#### *5.1.1.2. Make a Single Formula for Cost*

We want a single formula for cost = \$5.85 × Area of drawer = \$5.85 × ($4\times L_j \times h_j + 4 \times L_h^2$). And that is the cost when we know $L_j$ , and $h_j$. Therefore, the Cost = \$5.85 × ($4\times L_j \times \mathbf{0.6}/L_j^2 + 4L_j^2$) … (25), and computed to Cost be = \$5.85 × ($2/L_j + 4L_j^2$).

Table 5. Financial gains for the company when implementing the permutational drawers (VCPD )

| Situation | Trips capacities $m^3$/year | Trip Cost \$ per / transported $m^3$ | No. of Trips | | Total Trips' profit | | Financial gains | |
|---|---|---|---|---|---|---|---|---|
| | | | Company | EDT | Company | EDT | ROI \$ | % |
| | 1245.5 | | | | | | | |
| Before | 2235.2 | 13075.92 | 176 | ----- | 2301362 \$ | ----- | ----- | ----- |
| After | 2756.8 | 21917.03 | ----- | 295 | | 1373016.6 \$ | 928346 | 59 |
| | | | Reduction in \$ = 8841.1 \$ | | | | ----- | ----- |
| | | | Estimated annual gains (\$) ≅ 928346 | | | | | |

**5.1.2. The second step:** The drawers move up and down through the slots' stream and are controlled by ropes/chains that slide over horizontal pulleys; as shown in Figure-8 (Cooper, C., 2020a ), every drawer has mass m1, and another reciprocity moves in vice direction is $\mathbf{m}_2$. The design has two sides, the drawers' dimension, and the rope capability. Therefore, Eq. (26) and Eq. (27) discuss a simple EDT model that achieves the requirement. $T - m_1 \times g = m_1 \times a$ ... (26), while $m_2 \times g - T = m_2 \times a$ ... (27). When sum the two equations can expect with rope material used in a specific use case. $m_2 \times g - m_1 \times g = (m_2 - m_1) \times a$, then the acceleration of falling the full occupied is calculated the Eq. (28) $a = \frac{(m_2 - m_1)\times g}{m_2 + m_1}$ ... (28). Therefore, the tension required for completing the sliding motion is deduced from Eq. (29) $T = m_1 \times g + m_2 \times g$ ... (29). For example, if $\boldsymbol{m}_1$= 50 kg (full drawer) and $\boldsymbol{m}_2$=5kg (when empty), there is a need to move up and pull the full one down. The acceleration, in this case, is 8.035 $m/s^2$. While the tension required is 892.8 N. The design enhanced to achieve companies' requirements and reduce workers' fatigue 8.

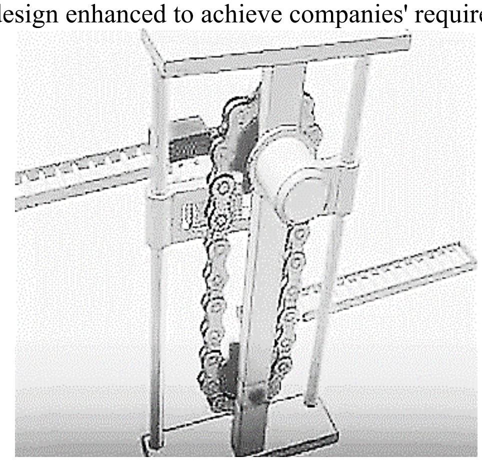


Figure 8. The rope mechanism

## 6. Conclusion

The digital twins are a future of development and control for transportation schemes to acquire adaptation skills (flexibility) to keep up with the VOC (i.e., the voice of customer) of satisfaction factors, whether the products or services are delivered in minimum time through distribution activities. The DT receives the VOC and/or stakeholders data fed to the IoT dataset to create a perception of steps to enhance and develop the designed product in its first generation schemes, discussed in Eqn. (1-24). Some of the indicators, such as the over-processing (waste) activities reduced by 27%, the average execution time of loading and unloading activities reduced by 40%, and the delivery time by 15%. The future of transportation lies in employing digital twins to increase serviceability for related KPI and cut expenses, which will become increasingly popular. By 2025, Up to 89% of all services must have their DT models controlled via IoT platforms in real-time. Nearly 36% of executives across various industries are aware of the benefits of digital twinning, with almost half aiming to implement it by 2028 (ASME, 2021). As time goes on, digital twin technology establishes itself as one of the essential software tools for changing product creation. The DT models are designed to study how to reduce the efforts, service time, service costs and increase the performance up to 59%, as shown in Table-5 (i.e., this value is different according to the studied case). Also, test, experiment, and develop the mechanism of the physical object to achieve the previous aims. The proposed EDT is ready to assume any inputs according to the use case to establish the presented object.

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