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AUTOMATIC DETERMINATION OF THE ARRANGEMENT OF GOODS ON A PALLET

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Abstract

Automated pallet loading layout determination is a key research area in logistics and industrial automation, directly affecting space utilization, transportation efficiency, and handling safety. Traditional manual and rule-based approaches are being replaced by optimization algorithms and intelligent systems capable of adapting to diverse product geometries and constraints. The increasing demand from e-commerce and just-in-time delivery highlights the importance of flexible and efficient palletizing strategies. Artificial intelligence and machine learning provide autonomous learning of optimal stacking schemes, while 3D simulation tools enable pre-implementation testing. Emerging trends emphasize the integration of collaborative robotics for real-time adjustment of layouts, supported by IoT technologies and smart sensors for enhanced precision. These developments contribute to reduced human error, improved energy efficiency, and sustainable logistics operations. Consequently, automated pallet layout determination is expected to become a fundamental component of next-generation supply chain systems.

Keywords*: Automatic, Pallet, Optimal, Logistic, AI.*

1 INTRODUCTION

Palletizing—the process of stacking goods on pallets for storage and transportation—is a fundamental operation in supply chains. The arrangement of products must ensure maximum stability, efficient space usage, and protection of the items during transit.

Palletizing goods in warehouses offers the following advantages:

- **Optimization of storage space**: grouping goods on pallets makes it possible to house a greater volume of products in the same space.
- **Increased productivity**: stacking products on a loading platform reduces the movements of operators and handling equipment, which can move a greater number of goods with each trip.
- **Streamlined storage and retrieval of goods**: palletized stock can be easily loaded and unloaded from the storage systems by means of suitable handling equipment.
- **Control of stored stock**: palletizing contributes to simpler inventory control by having a smaller volume of unit loads in the warehouse.
- **Higher throughput in loading and unloading**: the use of pallets allows operators — or automatic loading docks — to load and unload goods from trucks more quickly. Handling equipment can stack the goods and thus reduce the number of trips required.
- **Integrity of the goods during transportation**: the wrapping of the pallets prevents losses and damage to the packages or unit boxes during the distribution of the goods.
- **Safety in manual and automated warehouses**: palletizing limits the risk of damage and loss of stock while providing greater safety for goods, operators, and automatic equipment.

Traditional palletizing relies heavily on human labor, but with rising product variety and distribution speed requirements, automatic pallet arrangement systems is increasingly necessary, fig.1 [1].

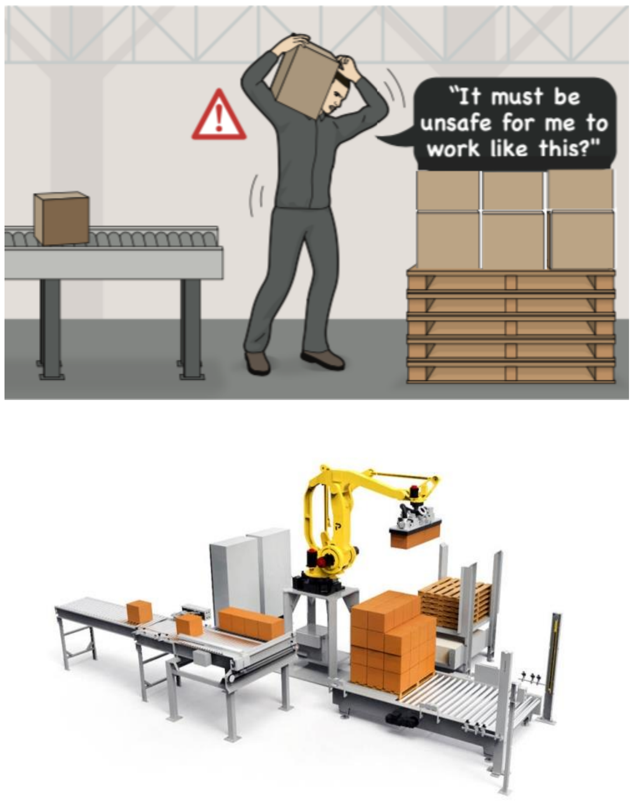

Fig.1 Manual [2] vs. Automated Palletizing[3]

2 PROBLEM DEFINITION

Automatic pallet arrangement seeks to answer:

- How to place different-sized items on a pallet without wasting space?
- How to ensure the load remains stable and safe?
- How to optimize for speed and adaptability?

This problem resembles a three-dimensional bin-packing problem, classified as NP-hard in computational complexity theory [4].

Constraints in Pallet Arrangement:

- Pallet dimensions: Standard sizes (e.g., 1200x1000 mm) vary by region. Palette EUR-EPAL is shown on Fig.2 [5,6].
- Item attributes: Weight, shape, and fragility.
- Stacking rules: Some products cannot bear heavy loads.
- Load stability: Center of mass must be close to the geometric center.

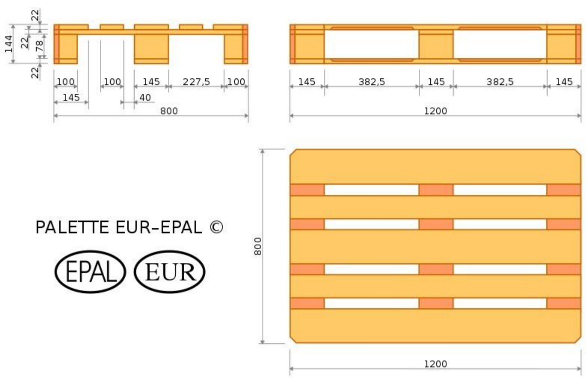

Fig.2 Palette EUR-EPAL

3 METHODS OF AUTOMATIC PALLET ARRANGEMENT

3.1 Rule-Based Heuristics

Simple methods use predefined rules: place heavier items at the bottom, stack similar sizes together, and avoid stacking fragile goods under heavier loads. Rule-based systems, however, are rigid [7].

3.2 Optimization Algorithms

Advanced systems employ:

- Greedy algorithms: Prioritize placement of the largest items first.
- Genetic algorithms (GAs): Mimic natural evolution to optimize load distribution [8].
- Mixed-integer programming (MIP): Solve for optimality under strict constraints.

3.3 Artificial Intelligence and Reinforcement Learning

Recent systems leverage:

- Reinforcement Learning (RL): Agents learn optimal palletizing through trial-and-error [9].
- Deep Learning: Neural networks predict efficient stacking patterns.

3.4 Architecture of an Automated Palletizing System

Key modules include:

1. Input Processing: Item scanning.
2. Planning Module: Optimization or AI-based computation.
3. Execution Module: Robotic handling.
4. Monitoring: Real-time feedback and adjustment.

There are many challenges of automated palletizing items. The main challenges are the following:

- Diversity of Goods
  Products varies widely in shape, weight, and fragility.
- Real-World Stability
  Physical behavior, like slippage and deformation, complicates theoretical solutions [10].
- Speed Requirements
  High-volume centers demand near-instantaneous computation.
- Robotics Integration
  Flexible robotic arms and grippers are needed for varying goods.

4 APPLICATION

Applications are found across:

- Warehousing
- Manufacturing
- Retail Distribution

Amazon, Walmart, and DHL are prominent adopters [11]. These tools calculate the best way to stack cartons, crates, or other packages on a pallet, aiming for:

- Maximum space usage (load density)
- Stability and safety
- Compliance with shipping rules (e.g., height/weight limits)
- Reduction in logistics costs.

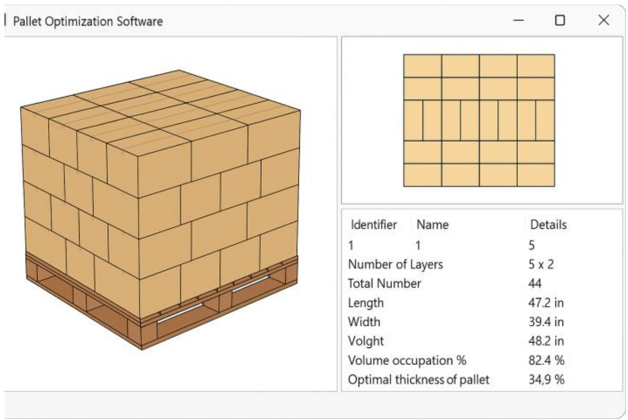

Fig. 3 *Screenshot of pallet optimization software*

4.1 Top Pallet Optimization Software Options (2025)

In table 1, main strengths of top pallet optimization software are presented.

Table 1 Main strengths of software

Software	Main Strengths	Ideal For
TOPS Pro	Very detailed pallet optimization, mixed product support, integration with ERP	Manufacturing, distribution, logistics companies
Cape Pack (Esko)	Palletization, carton optimization, supply chain visualization	Companies needing strong visualization and reporting
StackBuilder	Free, simple pallet and case optimization	Small warehouses, basic palletizing tasks
Palletization Studio (Cimcorp)	High-end pallet building with automation support	Robotic palletizing setups
PTV Load Optimizer	Truck loading + pallet optimization	Companies optimizing both truck and pallet loading
LoadBuilder	3D visual load planning, intuitive design	Transport and logistics service providers
FlexSim Pallet Optimization Module	3D warehouse/pallet simulation	Companies needing full warehouse flow optimization

Key functions of largest number automated pallet optimization software are:

- **Auto stacking patterns** (row-by-row, interlocking, column stack)
- **Mixed SKU palletization** (different products on the same pallet)
- **Custom pallet size support** (Euro pallet, CHEP, custom sizes)
- **Load stability analysis** (anti-tip, anti-slip calculation)
- **Export reports/drawings** for warehouse or customer use
- **Integration with WMS/ERP systems** (SAP, Oracle, etc.)

The future trends in development and application of automatic determination and optimization the arrangement goods on pallet, are:

- Physics-based simulations.
- Edge AI for on-device computation.
- Collaborative robots (cobots).
- Custom pallet design through additive manufacturing.

"Physics-based simulations" refer to computer simulations that model the behavior of physical systems by applying the laws of physics to virtual environments. These simulations aim to replicate real-world phenomena as accurately as possible, and they're widely used across many fields. Typically, physics-based simulations involve solving complex mathematical equations — often differential equations — using numerical methods and computer algorithms.

Edge AI for on-device computation refers to running artificial intelligence (AI) algorithms directly on local devices ("the edge") — such as smart phones, IoT sensors, drones, or autonomous vehicles — rather than sending data to centralized cloud servers for processing.

Key ideas behind Edge AI include:

- Low Latency: Decisions can be made in real time because there's no need to send data back and forth to the cloud.
- Data Privacy: Sensitive data stays on the device, improving security and compliance with privacy regulations.
- Reduced Bandwidth: Less data transmission reduces network load and operational costs.
- Offline Capability: Devices can operate and make intelligent decisions without internet connectivity

Collaborative robots (cobots) are a type of robot designed to work directly alongside humans in shared workspaces, fig 4[12], rather than operating in isolation like traditional industrial robots.

Fig.4 Collaborative robots (cobots)

Key features of cobots include:

- Safety: Cobots are built with force-limited joints, vision systems, and intelligent sensors to detect human presence and avoid collisions.
- Ease of Use: They are generally easier to program, often using intuitive interfaces like drag-and-drop programming or manual guiding ("teach-by-demonstration").
- Flexibility: Cobots can be quickly reprogrammed and redeployed for different tasks, making them ideal for small-batch production or changing workflows.
- Cost-effectiveness: Lower installation and maintenance costs compared to traditional robots, and no need for extensive safety barriers in many cases.

Cobots represent a major shift toward human-robot collaboration, combining the strengths of automation (speed, precision) with human capabilities (judgment, adaptability).

Custom pallet design through additive manufacturing means creating specialized pallets (the platforms used to support and move goods) using 3D printing or similar additive processes, rather than traditional manufacturing methods like wood or plastic molding.

Key ideas behind this approach:

- Customization: Additive manufacturing allows companies to design pallets tailored exactly to specific products — optimizing shape, strength, weight, and balance for the load.

- Light weighting: Materials like high-strength polymers or composite blends can be used to make pallets lighter without sacrificing durability, saving shipping costs.
- Complex Geometries: Pallets can be made with internal lattice structures, shock-absorbing zones, or integrated RFID tags and sensors, which are difficult or impossible to make with traditional methods.
- On-demand Manufacturing: Instead of storing large quantities of pallets, companies can 3D print pallets as needed, reducing inventory and warehousing costs.
- Sustainability: 3D printing can use recycled materials or produce designs that require less raw material overall, contributing to greener supply chains.

Materials typically used for 3D-printed pallets might include nylon composites, carbon fiber-reinforced plastics, or even recycled polymers.

5 CONCLUSION

In conclusion, automated pallet loading layout determination represents a decisive factor in achieving higher levels of efficiency, safety, and sustainability in logistics and supply chain operations. By replacing manual and rule-based methods with optimization algorithms, artificial intelligence, and simulation-driven approaches, palletizing systems can deliver superior adaptability to diverse product types and operational constraints. The integration of collaborative robotics and IoT technologies further enables dynamic, real-time adjustment and monitoring, ensuring precision and robustness in practical applications. These advancements not only reduce operational costs and human error but also contribute to energy efficiency and environmentally responsible practices. Consequently, automated pallet layout determination is poised to become an indispensable component of next-generation intelligent logistics infrastructures, driving innovation and competitiveness in global supply chains.

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