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An Investigation of Container Loading Problem Dealing with Irregular Shape Shipment

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Abstract

Container loading problem (CLP) is a category of problems that describing the scenarios of packing shipments into containers. It has been discussed in the fields of logistics, industrial engineering, transportation (civil) engineering, and operational management for many years. However, handling irregular shape shipment was not been investigated in-depth, such as algorithms of overlap searching, schemes of placing items, real world constraints, and damage control. This paper is dedicated to investigate and understanding the complexity and difficulties of the CLP involving irregular shape shipment, especially when closely related to industrial conditions. Beyond the previous works, the problem statement in this paper is formed with the idea of reflecting the real world scenarios and illuminating future research direction. In order to maximize the benefit of this paper to the industries, multiple methods and candidates are proposed that are collected from other fields. This paper includes overview of the factors related to irregular shape CLP that is worthy to concern while working on the next generation of great CLP approaches, particularly in handling irregular shape shipments.

Key words: *container loading problem (CLP), irregular shape shipment, metaheuristic methods, Semi-Knockdown (SKD)*

1. INTRODUCTION

Starting from the mid-1990s, the ongoing globalization and the incessant technology development, along with the increasing demand of shipping commodities around the world, made researchers realize the importance of figuring out new methodologies that help the industries to ship commodities more efficiently [1]. Research works reflect enormous amount of efforts from the academia, as well as the support from industries. There are several aspects of the container loading problems (CLP) which had been researched on, such as the typology of the CLP, categorizing the constraints, algorithms of overlap detections, nesting problem handling, and so on. After examining the literature, major efforts from the researcher were devoted into developing new algorithms using regular shape objects as their test samples. Regular shape objects in CLP represent those with relatively simple contours, for example, cuboid boxes, cylindrical items, and spherical ones. In contrast, "irregular shape" has two layers of meaning: objects with relatively complicated contours; a set of strongly heterogeneous objects with relatively complicated contours. One can easily argue the ambiguity of the term, "relatively simple/ complicated contours", when defining both regular shape and irregular shape objects. The major difference between regular and irregular shapes is that there will be a significant amount of space wasted when converting irregular shapes into the smallest regular shapes, such as applying oriented bounding box (OBB) or axis-aligned bounding box (AABB). In the literature, only one mentioned the idea once – rectangular shapes are regular and others are irregular [2]. However, recent literatures tend to treat those with much more complicated shapes as irregular shapes, such as sofa, stencils, and machinery parts. Judging from these differences, it is unquestionable that handling irregular shape shipment is much more complicated and challenging than dealing with regular shapes. This idea is supported the number of publications that discussed irregular shape shipments in CLP or related topics – 3 out of 167 publications between 1980 and 2011 [1]. It is noticeable that a huge gap between demands and supplies of methodologies for containerizing irregular shape shipments appears. Shipping irregular shape materials and parts takes place millions times every day around the world, commonly being adapted by industries from nanotechnology to mining equipment manufacturers. Lack of efficient methodologies for irregular shape shipments, there are only two options left for the industries: shipping products as they were regular shapes and wasting a huge amount of space; shipping products as irregular shapes by carefully design the packaging of the container but wasting a lot of time. No matter which way, it is eventually wasting of possible monetary profit. Therefore, it is a large market for developing methods and algorithms that efficiently handle irregular shapes in CLP with high accuracy.

The challenges encountered during planning shipping configurations involving irregular shapes include overlap detection, various material properties, different dunnage requirements, and so on. Furthermore, the stackability of the shipment also plays an important role in planning container layouts. Those factors and constraints will be discussed in detail later in this paper from the perspective that urging more attentions on CLP with irregular shapes.

In the paper, the mechanism of industrial CLP is covered that explained the difficulties associated with the irregular shape CLP. Advantages and disadvantages of several metaheuristic methods handling irregular shapes are compared. This paper will also discuss the constraints such as container size, stability control of the container, custom and highway regulations, easiness of loading and unloading, and so on. The last section summarizes the discussion and points to a research direction that fills the gap between industrial needs and research contributions.

2. A REAL WORLD NEED: MULTIPLE BIN-SIZE BIN PACKING PROBLEMS (MBSBPP)

This paper takes a containerization example from the leading agricultural machinery manufacturer, whose products are running in more than 80 countries on almost all the continents. There are many models of their products, for instances, a 13.6 L engine powerful tractor, are containerized in the way that disassembling the finished products into relatively chunks. Those chunks are semi-knockdown modules (SKD), which are relative easier to be disassembled and reassembled. SKD modules are irregular shapes in nature. For example (Fig 1.), it shows an engine SKD module from a tractor with irregular shape contours.

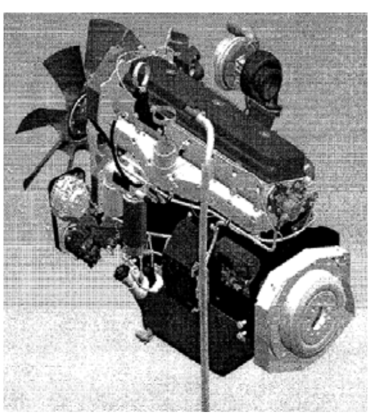

Figure 1. An engine SKD module from a tractor with complicated contours and over 1,400,000 triangles for meshes

Using bounding box to represent the engine takes 43% more space and its actual volume. Pioneers in CLP had established the typology for various scenarios that engineers encountered in real world challenges. Regarding to the typology of CLP, our case of containerization of SKD modules is categorized as a Multiple Bin-Size Bin Packing Problem (MBSBPP) with a set of additional constraints. MBSBPP stands for a type of CLP of "packing a strongly heterogeneous set of cargo into a weakly heterogeneous assortment of containers, such that the value of the used containers is minimized" [1]. In this case, there are more than 35 SKD modules per tractor, ranging from 2 kilograms intake pipe to 6 tons chassis. All those SKD modules are strongly heterogeneous judging from their shapes and physical properties, such as weight, requirements of dunnage, damage control, and so on. Therefore, this particular CLP along with all those constraints is not seen throughout the literature, but is commonly encountered in industries, everyday around the world.

After analyzing the relationships between those constraints and criteria, it is clear that this CLP can be optimized use cost oriented parameters (1). It is represented as the following

$$\min .C_{shpmt} = \sum_{k=1}^{K} R_k + \sum_{k=1}^{K} D_k + \sum_{m=1}^{M} P_m + \sum_{n=1}^{N} L_n + \sum_{n=1}^{N} F_n + \sum_{n=1}^{N} OT_n \tag{1}$$

where, C_{shpmt} is the cost for particular shipping action; R_k and D_k are the rate per container and damage cost per container; k is the index of containers, with total K containers; P_m is the cost of disposable pallets or dunnage; m is the index of pallets and dunnage, with total M pallets and dunnage; L_n, F_n, and OT_n are labor cost, facility cost, and overtime cost, respectively; n is the index of SKD modules, with total N SKD modules.

In this section, the information of containerization SKD modules and how irregular shapes influence the containerization process is discussed.

2.1 Containerization of SKD

Initiated from automobile industries, semi-knockdown (SKD) and completely-knockdown (CKD) are widely adopted techniques to increase the degree of containerization. SKD and CKD modules are designed to be conveniently reassembled to the final products after arriving to the overseas destination market [3]. SKD and CKD are both knockdown (KD) kits. The only difference between them is the level of knockdown, i.e. the size and completeness of the modules. Because of the more specific equipment and specialists needed for CKD, manufacturers prefer SKD gradually since mid-2000s [3]. SKD modules have the features of both small enough in size for containerization and large enough to minimize the troublesome induced by disassembling and reassembling.

Depending on the SKD modules, they may be allowed for stacking or not. Manufacturers assess the level of protections that required for shipping those SKD modules. Heavy SKD and high protection level SKD modules commonly require non-stacking packing inside the containers. SKD modules are normally placed onto pallets or into boxes for loading and unloading, as well as in-plant transportation.

Pallets and boxes that hold the SKD modules and other shipments are of wood, steel, plastic, or other affordable metals. Disposable pallets that made of wood need metal or plastic fasteners to secure the SKD modules. Reusable or recyclable ones are designed based on the idea of elevated durability and portability. A new trend of making manufacturing system more flexible is reconfigurable manufacturing systems [4], [5]. Emerging the new concept, engineers started to think adding reconfigurability to automation and carton boxes [6], [7]. By applying proper mechanisms and joints, pallets can be turned into reconfigurable in terms of changing the structure for different SKD modules. Reconfigurable pallets reduced the cost of dunnage by repeatedly using one pallet for different SKD, which suitable the pallet, throughout the entire life of the pallet. I may also be possible that folding the reconfigurable pallets into a more compact shape and shipping back.

Stability of the shipments inside the containers needs to be considered thoroughly as well, including sharp turns on trucks and high sea condition when on ships.

The overall center of gravity (CoG) and moment of inertia (MoI) are both the indicators of the stability of particular container. After designing the shipping configuration layout, in the form of container loading floor plans, one needs to consider the practicability of those plans. For example, the plans may worth nothing if one is not able to place the SKD modules to the specified location due to operational limits of a forklift in a tight space.

2.2 **Irregular shapes of SKD**

There are some occasional cases that SKD modules are packed in the boxes for shipping due to their small size or enhanced protection requirements. Other than those, SKD modules are often fastened onto stackable racks or open pallets, where only treating them as irregular shapes can help on achieving higher packing density.

During the investigation of the current containerization plans of that 13.6L engine huge tractor, it is found that the average space utilization is about 61.2%, while the weight utilization is slightly less than 75%. With these facts, the intuitive method flashes out – placing small SKD modules around the larger ones on the same pallet to utilize the space wasted by the large SKD module. Immediately following the formation of the aforementioned concept, the orientation of the SKD modules turns out to be the barrier that needs for planning as well.

Judging by the own shapes and the protection levels of the SKD modules, some are allowed to sit on multiple sides and some may not. SKD modules that are capable to be sit on multiple sides are with multiple axis-aligned orientations or possibly free-rotation positioning. The feasibility of multiple axis-aligned orientations depends on various factors, such as the weight, location of CoG, and the local structural toughness.

Unlike packing regular shapes, the overlap detection process takes much more efforts for irregular shapes. To detect overlaps in three-dimensional space, the two commonly used approaches are measuring the depth of overlapping; and, measuring the volume of overlapping. It is straightforward to see that both the approaches originated from measuring depth or area of overlapping in two-dimensional space. Using these approaches, resulting zero of the measurement is the goal for eliminating overlaps.

The focus then turns to the approaches that can effectively search for and eliminate overlaps locally and globally across the entire packing space. In two dimensional spaces, a fast-neighborhood search was proposed to search the whole area along axis-aligned paths (Fig. 2.) [8]. The method they used is combining guided local search and simulated annealing approaches to tackle the two-dimensional and three-dimensional overlap minimization nesting problem. However, the shortcomings for this approach stand out. The physical distance, or the gap, between each axis-aligned path is crucially important. Too small, it will take a significant amount of time for detection; too large, one may miss a just-fit spot for overlapping detection. This shortcoming needs much more efforts to compensate in three-dimensional searching.

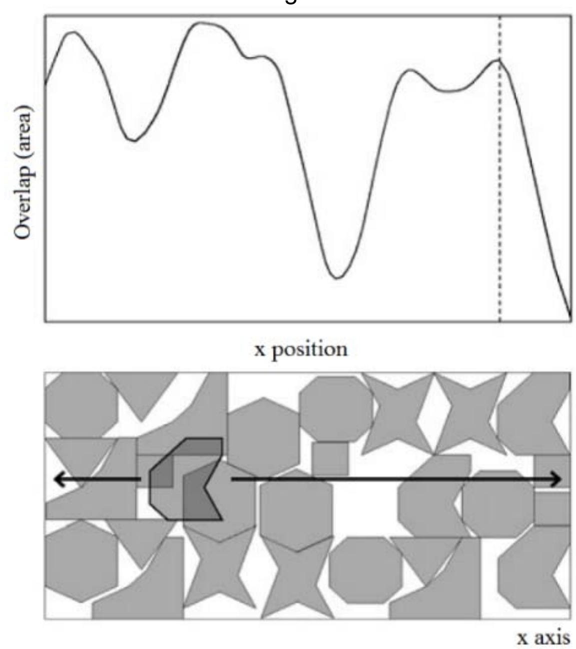

Figure 2. Illustration of guided local search for minimum overlap value along x-axis [8]. In the upper section, the vertical dash line indicates the right-most limit that the target objects can be placed inside the area entirely. This ensures no interference between objects and container.

Deriving from the concept of placing small SKD modules around the large ones to save space, one can group irregular shape SKD modules together into a number of irregular or regular shape sub-shipments. Those sub-shipments are much easier to handle for container-wise overlap detection and elimination. One of the benefits of this approach is that grouping does not require any predetermined characteristics or other prerequisites.

Collision free region (CFR), inner-fit polygon (IFP), and no-fit-polygon (NFP) are used to describe the suitable regions and overlapping regions of a two-dimensional polygon [9]. While the validity was shown in their publication, a considerable amount of the modifications up to the systemic level of the approach still need to be done before it can be applied to three-dimensional applications.

Challenges of overlap detection are only the tip of the iceberg. The irregular shapes can be treated as other irregular shapes, which are homeomorphism to the original one, or just close enough. In this way, the constraints in the CLP may be able to applied to the homeomorphic transformation in order to simplify the optimization efforts afterwards.

3. ALGORITHMS DEVELOPED IN IRREGULAR SHAPE SHIPMENT

In order to handle the irregular shapes, one needs to accurately represent the characteristics of shapes, and then apply overlap detection with proper orientations.

3.1 Recognition of the Shapes

To accurately represent the characteristics of irregular shapes, there are two major approaches: exact recognition and approximated recognition. The approximated recognition process disregards certain less important detailed information of the shapes. This approach simplifies the complex irregular shapes into reduced shapes, which greatly reduces the computational efforts over exact recognition. Therefore, approximated recognition is more reasonable than exact recognition when tackling CLP with irregular shapes, especially for complicated SKD modules.

Currently, the most popular approximated recognition is adopted from the raster model (Fig. 3.) originated from geographic fields. Now, this approach contributes to almost all imaging related fields.

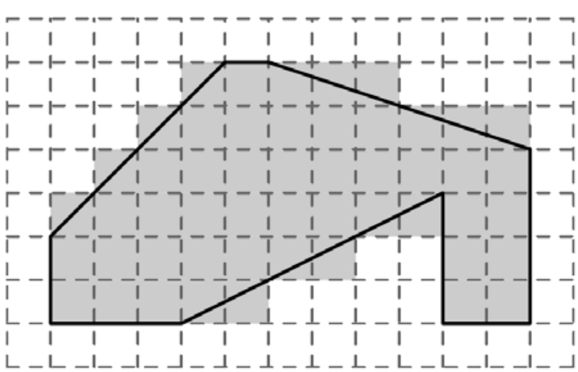

Figure 3. Example of how raster model works [8]

Raster model has an important factor, cut-off ratio, which is used to regulate the percentage boarder between occupied and unoccupied cells. For those SKD modules with far more complicated shapes, this paper introduces two more factors for keeping important characteristics along with the simplified shape and improving the capability of constraints. One is the shape regulating ratio. It measures how closely the irregular shape segments are rounded up to their bounding boxes. The other is the round-up level. It measures the cell size, which is defined as the number that greater than a certain length of the longest edge of the irregular shape segment's bounding box. With these two additional factor, the engine assembly SKD module is transformed into its three-dimensional irregular shape, the envelop shape (Fig. 4.).

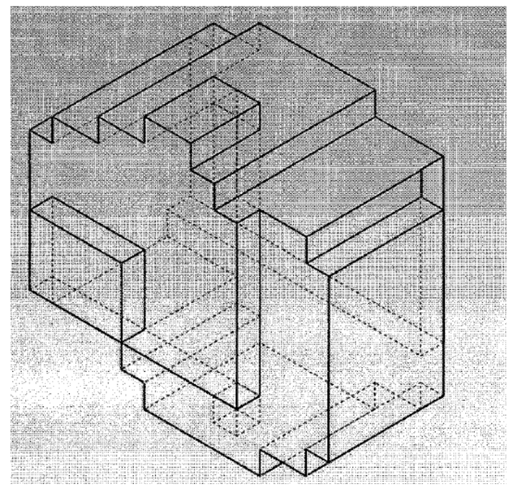

Figure 4. The engine SKD mentioned previously is simplified to this three-dimensional irregular shape with 50% cut-off ratio, 100% shape regulating ratio, and 10 cm round-up level

This simplification process is named as pixelation. It has the capability of considering the constraints, such as stability, interference, damage-free, and so on. The Pixelation cut-off ratio is related with round-up level. By carefully adjusting the combination of cut-off ratio, shape regulating ratio, and the round-up level, one can actually embed a certain thickness of cushion around the irregular shapes. That is to say, it is no need to add extra gap between objects if with the cushion. Improper combined parameters may result under-profiled envelop shapes, which put shipments at the risk of interference damage (Fig. 5.).

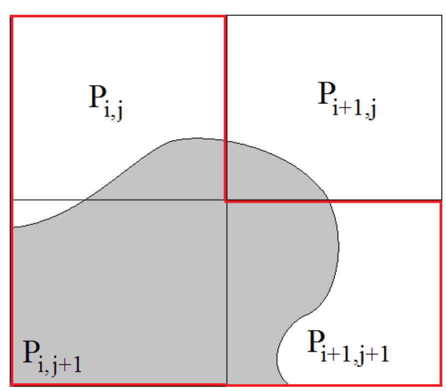

Figure 5. Possible under-profiled envelop in red cells due to improper combination of cut-off ratio, shape regulating ratio, and round-up ratio. The irregular shape (shaded area) sticks out of the envelop shape.

3.2 **Orientation of the Irregular Shape SKD Modules**

Depending on the properties of the SKD modules, the optimal orientations in the container are restricted by the constraints.

3.2.1 *Fixed Orientation*

There are several constraints that may result the SKD modules have only on available orientation. One needs to fully consider almost every aspect of the constraints before actually putting efforts to developing heuristic methods.

Support constraints representing the SKD modules may only have one or two surfaces that are available for mounting and fastening onto the pallets. Then, those surfaces must facing specific directions for mounting properly.

Floor load distribution limitation stands for the scenario that specific orientation needs to be followed to ensure the floor load distribution of the container falling into certain limitations.

CoG and MoI reflect the container stability requirements that are predetermined by the regulations. Lower and centered CoG and smaller MoI are always preferable. Moreover, certain orientation of certain SKD modules must be applied in order to achieve the CoG and MoI requirements.

Loading process limitations are the conditions that the orientations of the SKD modules are limited due to the operational practice of the proper equipment are used when loading and unloading SKD modules, as well as loaded pallets.

3.2.2 *Limited variation of orientations*

SKD modules with limited variation of orientations are those have a certain level of flexibility on different orientations. The idea of virtual subset was tested [10] when dealing with CLP with irregular shape furniture shipments. The shipment items are grouped into “subsets” by combining the highest total profit transported with given size of containers. The value of each shipment item is predetermined by the manufacturer, such as the price, rush or not, and so on. This heuristic method solves the subset loading problem one after another. Different grouping schemes were employed to fulfill the requirements of protecting large shipment items during transportation.

The mechanism under the hood of this heuristic method is prioritizing the loading sequence of the items with different level of desirability associated with them. This type of CLP is categorized as strongly heterogeneous three-dimensional single knapsack problem (SKP) with irregular shapes by using the improved typology of CLP [11]. However, this heuristic method is limited by its assumptions: axis-aligned rotation based orientations; smaller items are allowed on top of the larger ones; and larger shipments have higher desirability.

Another structural condition raised by the above heuristic method, when placing a sofa onto another. The real life experiences tell us that the portions the sofa in contact with each other will deform due to force. However, this observation was not reflected in the aforementioned heuristic algorithms.

That is to say, in order to solve the real world problem, one has to use real world observation to identify the actual situation.

3.2.3 *Full possibility of orientations*

If there is no explicit constraint for some SKD modules, they are considered as the ones with full possibility of every pose. New algorithm was introduced for handling two- and three-dimensional Knapsack Packing Problem (KPP) for regular shape containers, as well as regular shape objects [10]. It assumes orthogonal packing for regular shapes, along with the principle axes of the containers. It is an iterative heuristic method based on very-large-scale integration (VLSI) module placing, which is originated from rectangular-packing with sequence pair in chip design industries.

This method was proved to be more efficient than the previous one that dealing with SKP in three-dimensional space. Therefore, it is possible to develop better algorithm based on the above one for irregular shapes.

4. DEALING WITH DIFFERENT CONTAINERS

Containers have been widely used in cargo shipment in the world. Its sizes range from 10-foot ISO container to 53-foot North American container. Among them, the twenty-foot ISO container is used as a unit for the amount of cargo. TEU stands for twenty-foot equivalent unit.

Meanwhile, categorizing by the purposes of the containers, there are 9 common types: dry storage container, flat rack container, open top container, tunnel container, open side storage container, double doors container, refrigerated ISO container, insulated/ thermal container, and cargo storage roll container.

When dealing with CLP, one should make sure the available types of containers in hands. Basically, single type of containers and multiple types of containers are the two situations that describe the availability of containers.

4.1 **Single type of containers**

Single type of containers scenario sets the type of available containers to only one, but not the number of total containers. This scenario is usually resulted from the special requirement of the SKD modules that only certain container can fulfill. With only one type of container, the initial empty space is fixed to the inner size of the container, which is relatively easy to handle.

4.2 **Multiple types of containers**

Multiple types of containers scenario sets the types of available container to a certain number, with specified types of them. The scenario started with the following situation: a set of SKD modules takes a little more space than one 40-foot ISO container, but less than two of them. The manufacturer will waste of significant amount of profit by using two 40-foot ISO containers. If enable multiple types of containers option, the manufacturer may be able to ship those SKD modules in one 40-foot ISO container and one 20-foot ISO container. However, the downside of this scenario is the initial packing space is not fixed, a bad news for programmable packing algorithms. Fortunately, one can set the initial empty space as the largest available container, and then the smaller one, and so on. Or, if it is possible, one can estimate the volume of the SKD modules and choose the initial container wisely. The way of prioritizing the initial container is very similar to the algorithms mentioned previously, prioritizing furniture [2], [9].

Apart from the single type of containers and multiple types of containers, there is one more scenario that one could benefit from – shipping unexpected or ungrouped SKD modules along with sets of SKD modules to fill up the possible empty space left over. An example of this scenario is shipping spare parts of the machineries along with the SKD modules from several sets of finished products. Under this condition, the sets of SKD modules have higher priority. It is because that the destination facility cannot finish reassembling process until the full set of SKD modules arrives.

5. STABILITY OF CLP WITH IRREGULAR SHAPES

Ensuring damage-free of the containers is not only the carriers duty, but also the manufacturers' duty. The time and labor lost may never be monetarily compensated if damages occurred during shipping. Furthermore, a good design of the shipping configuration is beyond packing as much as possible. The stability of SKD modules inside the containers should be able to filter certain unexpected unstable external conditions. Engineers need to take both the stability conditions on sea and on road into account. Factors involved are vertical vibration frequency and amplitude, horizontal acceleration, and angular acceleration.

With meta-heuristic Guided Local Search (GLS), a newly proposed method managed to reduce the augmented objective function, which including container balancing, MoI, and overlap detection [12]. Their approach minimizes the MoI of the container by minimizing the differences between a predetermined overall CoG target and the CoG of the shipment items that are being placed. The above approach demonstrated valuable results in controlling MoI of the container. However, there is one concern that the aforementioned approach did not tackle. Placing a light weight SKD module and a heavy weight SKD module at the same location have different effect to the change of MoI. In other word, the negative effect due to an earlier placed heavy SKD module may not be compensated by wherever the rest of SKD modules are placed. This scenario can be observed if only two heavy SKD modules and many light weight SKD modules are formed as a set of shipment.

When considering the stability of container on sea, the nature of the wave makes the low frequency and high amplitude roller-coasting type movements the most challenge constraint. The average frequency the sea wave, even on high sea condition, is as low as 0.5 Hz, while the amplitude can exceed 20 meters [13]. Depending on the size the container ship, the longitudinal and lateral inclinations of the container ship may achieve over 40 degrees. The angular velocity and acceleration corresponding to the roll and pitch direction of the ship need to be considered for the design of the shipping configuration.

Transporting containerized cargo on road introduces the vertical vibration with up to 10 Hz in frequency and 0.5 meter in amplitude, depending on the road condition and suspension performance [14]. Moreover, steep turns and wobbling motions on highway and local roads create horizontal shifting and rotation in yaw direction of the containers on trucks traveling in high speed.

5.1 Static load and axle load

Static load is the load exerting on the floor of the container contributed by the SKD modules in static manner. Different containers have their own limits for the wooden floor in terms of pressure concentration. Loading SKD modules with pallets and racks helps on distributing pressure more evenly and more controllable. Axle load measures the loads on each axle of the trucks on the scale.

United States Department of Transportation (USDOT) holds specific regulations on not only the gross weight of the truck, but also maximum axel load corresponding to various types of the axels (Table 1.).

Table 1. Weight allowance of trucks enforced by USDOT

Limitation Type	*Maximum Allowed Load (lb.)*
Gross Weight	80,000
Steering Axle	12,000
Trandem Axle	34,000
Tridem Axle	42,000

That is to say, engineers need to adjust the target CoG and corresponding weight of the truck and trailer to ensure the axle load in the legal range, as the axle load including truck and trailer themselves.

5.2 Dynamic load on road

On a perfect horizontal road, the containers are actually in the inclination status with the front end pitching up. When driving up or down of a ramp, the inclination will change the force components that exerting on the SKD modules inside the containers. Moreover, driving through a speed hump or on a bumpy road will create more dramatic and sudden change of the direction of acceleration, even hard downward impact on the container floor. The potential damage under the above conditions is related to the equipment that installed on the truck, steel leaf suspension or air-ride, as well as the safety margin of the shipping configuration.

6. CONSTRAINTS OF CONTAINER LOADING PROBLEMS WITH IRREGULAR SHAPES

As mentioned at the beginning of this paper, irregular shape shipments induced a lot more constraints than regular shape shipments. Cushion is one of the most important constraints but received one of the least attentions from researchers. Other constraints, such as facility availability, easiness of loading and unloading, and operability with equipment, are also factors involved in dealing with irregular shape shipments.

However, due to the relative lower importance and insignificant of effects after tackling, they are not covered in this paper. On the other hand, both regular shape and irregular shape shipments face the same constraint – compatibility between commodities.

6.1 **Cushion between commodities**

Cushion stands for both the physical dunnage and the virtual gaps between SKD modules. Physical dunnage can absorb the energy in case of impact, while virtual gaps give SKD modules room to prevent potential impact. Properly designed envelop shapes of the shipments include the virtual gaps in between to reduce not only potential impact but also potential interferences when loading and unloading. Leaving sufficient gaps in between SKD modules in the design phase of the shipping configuration can provide rooms for error that might occur by transporting SKD modules in-plant and on/ off the containers.

6.2 **Compatibility between commodities**

Border controls of each government have their own regulations that restrict the forms of the commodities entering their regions. There is a code associated with each commodity for each border controls and customs. It is a commonly shared rule that the import tax of the complete product is higher than parts of that same product. Therefore, manufacturers frequently negotiate with custom authorities on the categories of each SKD should fall into, which greatly change the tax rate.

The underlying mechanism of this rule also restricts the possible combination of the SKD modules, which are placed in the same containers. For instance, wheels and axles from the same tractor have their own commodity codes. If placing wheels and axles in the same container, the ability of assembling them create a new commodity – wheel & axle assembly – elevating the import tax over 30%.

The intuitive solution for this constraint is developing the compatibility library listing the restricted or allowed combinations of the SKD modules.

7. CONCLUSION

This paper compared the challenges induced by handling irregular shape shipments in container loading problems. Using the real world cases as examples, this paper illuminated the rarely researched CLP scenarios with the perspective from semi-knockdown modules. Several heuristic methods are highlighted in this paper to emphasize the possibilities of those methods towards the future meta-heuristic methods for dealing three-dimensional irregular shapes. Multiple constraints, such as cushions, stability, types of containers, orientations of the SKD modules, and the compatibility between SKD modules, are also discussed more or less. This paper proposed several possible solutions or directions of research that might contribute to the industries, for example, pixelation and envelop shapes. In summary, there are still a plenty of gaps to be researched in the field of handling irregular shapes in container loading problem.

8. REFERENCES

[1] Bortfeldt, A. and Wäscher, G. (2012), “*Constraints in container loading – A state-of-the-art review*”, European Journal of Operational Research, vol. 229, no. 1, pp. 1–20.

[2] Egeblad, J., Garavelli, C., Lisi, S., and Pisinger, D. (2010) “*Heuristics for container loading of furniture*”, Eur. J. Oper. Res., vol. 200, no. 3, pp. 881–892.

[3] Miller, R. (2000), *Doing business in newly privatized markets: global opportunities and challenges*. Quorum.

[4] Mehrabi, M., Ulsoy, A., and Koren, Y. (2000), “*Reconfigurable manufacturing systems : Key to future manufacturing*”, Journal of Intelligent Manufacturing, vol. 11, no. 4, pp. 403 – 419.

[5] Mehrabi, M., Ulsoy, A., Koren, Y., and Heytler, P. (2002), “*Trends and perspectives in flexible and reconfigurable manufacturing systems*”, Journal of Intelligent Manufaturing, vol. 12, no. 2, pp. 125 – 146.

[6] Dai, J., Medland, A., and Mullineux, G. (2009), “*Carton Erection using Reconfigurable Folder Mechanisms*”, Packaging Technology and Science, vol. 22, no. 7, pp. 385–395.

[7] Yao, W., Dai, J., Medland, T., and Mullineux, G. (2010), “*A reconfigurable robotic folding system for confectionery industry*”, Industrial Robot: An International Journal, vol. 37, no. 6, pp. 542–551.

[8] Egeblad, J., Nielsen, B., and Odgaard, A. (2007), “*Fast neighborhood search for two- and three-dimensional nesting problems*”, European Journal of Operational Research, vol. 183, no. 3, pp. 1249–1266.

[9] Sato, A., Martins, T., and Tsuzuki, M. (2012), “*An algorithm for the strip packing problem using collision free region and exact fitting placement*”, Computer-Aided Design, vol. 44, no. 8, pp. 766–777.

[10] Egeblad, J. and Pisinger, D. (2009), “*Heuristic approaches for the two- and three-dimensional knapsack packing problem*”, Computers & Operations Research, vol. 36, no. 4, pp. 1026–1049.

[11] Wäscher, G., Haußner, H., and Schumann, H. (2007), “*An improved typology of cutting and packing problems*”, European Journal of Operational Research, vol. 183, pp. 1109–1130.

[12] Egeblad, J. (2009), “*Placement of two- and three-dimensional irregular shapes for inertia moment and balance*”, International Transactions in Operational Research, vol. 16, no. 6, pp. 789–807.

[13] Mitra, S., Wang, C., Reddy, J., and Khoo, B. (2012), “*A 3D fully coupled analysis of nonlinear sloshing and ship motion*”, Ocean Engeering, vol. 39, pp. 1–13.

[14] Singh, S, Saha, K., Singh, J., and Sandhu, A. (2012), “*Measurement and Analysis of Vibration and Temperature Levels in Global Intermodal Container Shipments on Truck , Rail and Ship*”, Packaging Technology and Science, vol. 25, no. 3, pp. 149–160.

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Primljen (24.05.2015.); Recenziran (27.06.2015.); Prihvaćen (03.07.2015.)

Apstrakt

Problem utovara kontejnera (CLP) je kategorija problema koji upisuje scenarije pakovanja pošiljki u kontejnere. O problemu se govori na polju logistike, industrijskog inženjerstva, saobraćaja i operacionog menadžmenta već dugi niz godina. Međutim, rukovanje pošiljkama nepravilnog oblika nije istraženo suštinski, na primer pomoću algoritama traganja preklapanjem, shema postavljanja predmeta, ograničenja u stvarnom svetu i kontrole štete. Ovaj rad je posvećen istraživanju i razumevanju kompleksnosti i poteškoća CLP-a vezanih za pošiljke nepravilnog oblika, posebno kada su usko vezani za industrijske uslove. Za razliku od prethodnih radova, problem u ovom radu je definisan sa idejom da se reflektuju realni scenariji i osvetle budući pravci istraživanja. Kako bi se povećala korisnost ovog rada u industriji, predloženo je više metoda i kandidata sakupljenih iz drugih polja. Rad sadrži pregled faktora vezanih za nepravilni oblik CLP-a koji je potrebno razmatrati kada se radi sa sledećom generacijom velikih CLP pristupa, posebno prilikom rukovanja pošiljkama nepravilnog oblika.

Ključne reči: *problem utovara kontejnera (CLP), pošiljke nepravilnog oblika, metaheurističke metode, polu-gotovi proizvodi (SKD)*