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A Universal Mobile Packaging Line and its Operating Capability Simulation

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Abstract:

The paper presents a universal mobile packaging line prototype as the outcome of a defence development project assigned by the Ministry of Defence of the Czech Republic. It is a facility designed for disassembling military as well as other material, and assembling supply units on standard-size disposable pallets suitable for road and air transportation. In the practical part, basic tactical-technical data of the universal mobile packaging line and its operating capabilities are determined using simulation software and the queuing theory.

Keywords:

Container ISO 1C, configured load, mounted hall, pallet unit, queuing theory, simulation

1. Introduction

One of the key military capabilities is the sustainability of units in various types of military operations. The goal of the project was to design a modern facility which would make supply assembling more effective, improve stock recording and tracking, enable data communication with the Information System for Logistics (ISL), and reduce labour intensity of unit supplying process in the Czech Armed Forces (CAF).

2. Main Universal Mobile Packaging Line (UMPL) Actions and Functions

The outcome of the development project is a prototype of a Universal Mobile Packaging Line (UMPL) with operational and technical documentation for the prototype manufacturing. VOP CZ, s. p. company was the researching entity.

The Universal Mobile Packaging Line enables disassembling selected supplies stored in ISO 1 containers up to the size of a group or piece packaging, and assembling new (as actually required) supply sets on disposable pallets. The "selected supplies"

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refer to food, packed water, medical material and other common products. Fuel and lubricants, hazardous chemical substances and ammunition, with the exception of infantry ammunition, shall not be handled in the UMPL [1].

The UMPL technological equipment and instrumentation also enables:

- pallet unit shrink- or stretch-wrapping;
- pallet labelling using labels with prescribed data structure required for consignment recording, transportation, receipt and tracking;
- stocking pallet units at a depository;
- recording material input and output using bar code readers and the ISL (only unclassified data processing).

The UMPL technological equipment enables assembling and packaging pallet units of standard size (800 × 1,200 mm).

The packaging line design allows loading several classes of supply on one pallet. Assembled material on a pallet is strapped using an automatic strapping machine and stretch-wrapped in order to protect the material from climatic effects.

Typical pallet handling units (small height, shape variability and asymmetry, weight below 80 kg etc.) are packed manually using hand strapping tool and film reel, which are kept in packaging tables.

The main UMPL operation parameters are as follows:

- the line capacity is up to 20 pallets per 1 hour depending on the material disassembly/assembly demands. In total, a UMPL is operated by 10 trained workers;
- readiness to perform required tasks after the arrival at the place of deployment is achieved within 96 hours;
- capability of independent operation at the place of deployment without having to replenish consumable supplies and fuel for the period of min. 24 hours;
- capability of all-year operation in climatic conditions as per AECTP-200, edition 4;
- a UMPL may be powered by means of a power generator having minimum capacity of 60 kW [2].

3. A UMPL – Basic Parts

A UMPL comprises of the following parts:

- the main handling and assembly workplace (a prefabricated hall with textile sheathing, EURO UT type 15 × 24 × 6.8 m, floor boards, wiring and lighting set, packaging tables);
- means of crypto climate maintenance;
- an administrator workplace (a thermal-insulated ISO 1C container, air-conditioning and ventilation equipment, heating, electrical wiring, purpose-built structures and equipment);
- a packaging and labelling workplace (a thermal-insulated ISO 1C container, air-conditioning and ventilation equipment, heating, electrical wiring, packaging line equipment, purpose-built structures and equipment);
- UMPL application software;
- auxiliary means of handling pallets, material to be packed and waste material;
- basic and other equipment to replenish the workplace with consumables;
- 9 ISO 1C containers for the transportation and storage of UMPL parts.

The main handling and assembly workplace is situated in the prefabricated hall with a thermal-insulation insert; the hall has 4 entrances and a connecting module on the front wall for the administrator container and the packaging and labelling workplace container attachment. The entrances in the right side wall are intended for piece material input, personnel entering and leaving, and waste or excessive material removal. Entrances in the left side wall are intended for pallet material input, including air-cargo (air-land) 463L pallets.

In the prefabricated hall, an extendible roller conveyor is situated, which conveys piece material in packages (boxes) to the workplace through the side entrance, and a module conveyor line, comprising 4 sections. The first section of the module conveyor line is designed for the input of pallet material meant for repackaging without disassembly. The following 2 sections are designed for the assembly of pallet units using disposable four-way pallets sized $1{,}200 \times 800$ mm, including their subsequent transportation, packaging and dispatching. The final section of the conveyor line is designed for pallet unit conveying to the packaging and labelling workplace, and is equipped with a weighing device module and a centring device module. At the control panel of the packaging line a barcode reader is placed. It is used to retrieve the appropriate packing list of each pallet unit before validation and packaging. On one of the packing tables is installed the smart cards reader – the equipment for printing packing lists and workers'.

The packaging and labelling workplace is situated in an ISO 1C container, and comprises an automatic strapping machine, a rotating pallet stretch wrapper and the inbuilt end section of the conveyor line. The inbuilt section is equipped with a revolving table, on which pallets are turned while being strapped, and an output tilting module. The conveyor module also serves for pallet unit labelling, and the tilting part enables storing pallet units for distribution. The label printing machine is located in the rear part of the workplace.

The administrator workplace is equipped with ISL-connectable computers with newly developed UMPL application software with material recording and configured loads creating, and a label and packing list printing machine, including a platform for workers' registration using contactless smart cards. At this workplace, documents, operators' personal belongings and detergents are also kept.

4. Simulation

4.1. Model Assumptions

In 2012, the UMPL was operated on a trial basis with the aim to verify the line capacity and functionality. Based on the trial operation output generalisation, allowing empirical determination of the UMPL input character, a mathematical model was developed with the following assumptions:

- the model serves for testing supply set (pallet units) assembly for a model task force,
- selected high-consumption materials (bottled water, combat rations, accoutrements, etc.) are used for the supply set assembly,
- the materials are stored in distribution containers mainly of regular block shape with dimensions complying with the basic module 600×400 mm as per [3],
- the number of operators and their job content follow from the declared UMPL tactical-technical data,

- no pallet unit load plans are available; only the operators' experience is taken into consideration.
- pallet units are not labelled during assembly, and the accompanying documentation is not attached,
- the time required for pallet unit labelling and working out the accompanying documentation (e.g. content sheets) is not included in the pallet unit assembly time,
- the assembly of material on disposable pallets is assumed so that the assembled pallet unit centre of gravity is in the ideal centre in relation to coordinates in a virtual T coordinate system: [600; 400],
- potential UMPL error rate caused by the setting, technical faults or operators (e.g. strap sliding off during strapping) is not taken into consideration.

4.2. Simulation Model

The universal mobile packaging line comprises three inputs – input1, input2 and input3 – in Fig. 1 these correspond to positions 4, 6, and 10. At the inputs, pallet units are disassembled, or assembled before being ready to enter the service section of the line (system) – from position 11 onwards.

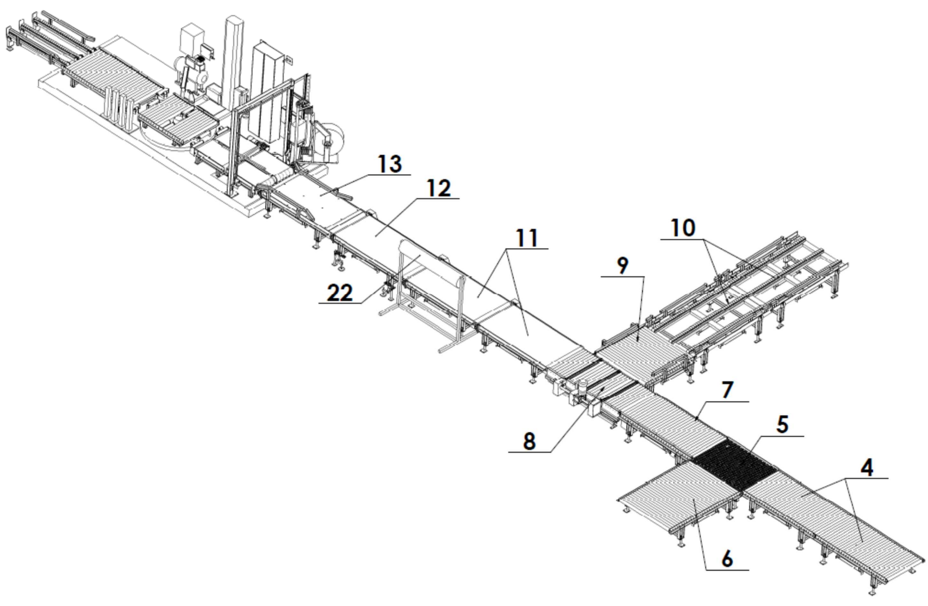

Fig. 1 UMPL Scheme [4]

The work carried out on pallet units at a respective input lasts for certain time, which is a random quantity, whose distribution was obtained empirically separately for individual inputs based on trial operation experience. In MATLAB interactive programme environment, m-files assembly1.m, assembly2.m and assembly3.m were modelled. These three m-files model above-mentioned random quantities – the time required for pallet unit preparation at input1, or input2, or input3. Each of the sets (programmes) returns the random quantity value with the distribution.

A queuing model of G/G/1/3 type was applied to the service proper – system (from position 11 onwards) and the system characteristics description. In Kendall's notation [5] it means that the distribution of the time between two consecutive request arrivals (here the pallet unit) in the system is random (the first "G" symbol), the system service time distribution is random (the second "G" symbol), there is one service line (the "1" symbol), and the system is limited – maximum number of pallet units in the system is three (the "3" symbol). The only input in the G/G/1/3 system, i.e. in the service proper, in fact comprises the three above-described inputs. The random quantity – the time between two arrivals in the system (in the service proper) is modelled using three random quantities relating to the inputs: input1, input2 and input3. For such purpose, an assembly.m programme was developed in MATLAB. The service time, i.e. the time of wrapping, strapping, interoperation handling etc. from position 11 onwards is again a random quantity; that is a function of pallet unit height. The pallet unit height is a random quantity again; its distribution was obtained empirically from the trial operation – it ranged from 600 to 1600 mm.

In MATLAB, an MHO_UMBL3a.m programme was developed simulating the line operation. Its only optional parameter is the number of pallet units entering the system marked as *k*, and represents the number of "steps". The output is the matrix of ***k*** × ***4*** type, i.e. a matrix with *k* lines and *4* columns.

In the *i*th line, the vector is [*t*(*i*), *Nvst*(*i*), *Nvyst*(*i*), *N*(*i*)], where:

- *t*(*i*) is the time (in seconds) of the pallet unit number change, i.e. the time within which a pallet unit entered or left the system,
- *Nvst*(*i*) refers to the number of pallet units entering the system (quantity not decreasing over time),
- *Nvyst*(*i*) is the number of pallet units leaving the system (quantity not decreasing over time),
- *N*(*i*) is the number of pallet units (currently) in the system.

All in *i*th step, for $i = 1, 2, \dots k$.

Based on the above-described output, basic system characteristics were calculated as follows.

If the number of steps is sufficient ($k \gg 10$, e.g. $k = 10{,}000$), the average number of pallet units passed through the system (having left the system) per a unit of time can be expressed as:

$$Intensity = \frac{Nvyst(k)}{t(k)} \tag{1}$$

Interval $\langle t(i), t(i+1) \rangle$ is the *i*th time interval, $i = 1, 2, \dots k - 1$. Its length is:

$$\Delta t(i) = t(i+1) - t(i) \tag{2}$$

Within this interval, the number of pallet units in the system equals *N*(*i*). The total time, when the system is empty, is calculated as follows:

$$t(N = 0) = \sum_{\substack{i=1 \\ N(i)=0}}^{k} \Delta t(i) \tag{3}$$

where the time intervals $\Delta t(i)$, for which $N(i) = 0$, are summed.

Analogically, the total times with exactly 1, or 2, or 3 pallet units in the system, are determined. It is clear that these partial times add up to the total time, i.e. it applies:

$$t(N=0)+t(N=1)+t(N=2)+t\,(N=3)=t(k) \tag{4}$$

The probability that there are exactly n pallet units in the system can be calculated as follows:

$$P(n)=P(N=n)=\frac{t(N=n)}{t(k)}, n=0,1,2,3 \tag{5}$$

The probability that the system capacity is fully used is $P(3) = P(N = 3)$. With this probability, a request intending to enter the system will be rejected.

The number of pallet units in the system is a discrete random quantity. It can have the value of exactly 0, 1, 2, 3 with probabilities $P(0)$, $P(1)$, $P(2)$, $P(3)$. The average number of pallet units in the system can be calculated using the discrete random quantity mean value equation, i.e.:

$$\bar{N}=\sum_{n=0}^{3} n\cdot P(n) \tag{6}$$

The MATLAB interactive programme environment output for 10,000 steps (k = 10,000) is as follows:

```
>> V=MHO_UMBL3a(10000);
>> [poc,prum,t,P]=UMBLchar(V)
poc =
    2.3386
prum =
    0.0051   0.3052   18.3143
t = 1.0e+005 *
    0.4294   1.3923   2.4248   5.5780
P =
    0.0437   0.1417   0.2468   0.5678
```

Considering all the above-specified characteristics and data:

- the average number of pallet units in the system is $\bar{N}=2.3386$ pallet units,
- the line capacity – the average number of pallet units leaving the system equals 18.3143 pallet units/h (0.0051 pallet units/s; 0.3052 pallet units/min),
- the probability that there is exactly 0 (or 1; 2; 3) pallet unit(s) in the system equals 4.37 % (or 14.17; 24.68; 56.78 %),
- the probability that the system capacity is fully used is $P(3)$ = 56.78 %.

The output from the simulation of UMPL operating parameters can be represented in a graph (see Fig. 2). In one graph, the dependency of three obtained quantities (*N*, *Nvyst*, *Nvst*) on time is shown.

5. Conclusion

The UMPL is currently in use at a respective CAF supply centre for the distribution of supplies from the national area to the area of operation. In case of need, the UMPL is predetermined to brigade and battalion task force supplying. The UMPL deployment is considered in a logistics base (LOGBASE) area, or possibly in other areas depending on the security situation. Assembled pallet units shall be conveyed on demountable load-carrying platforms, platform vehicles or by air to the place of destination, or, as a variant, directly to combat units.

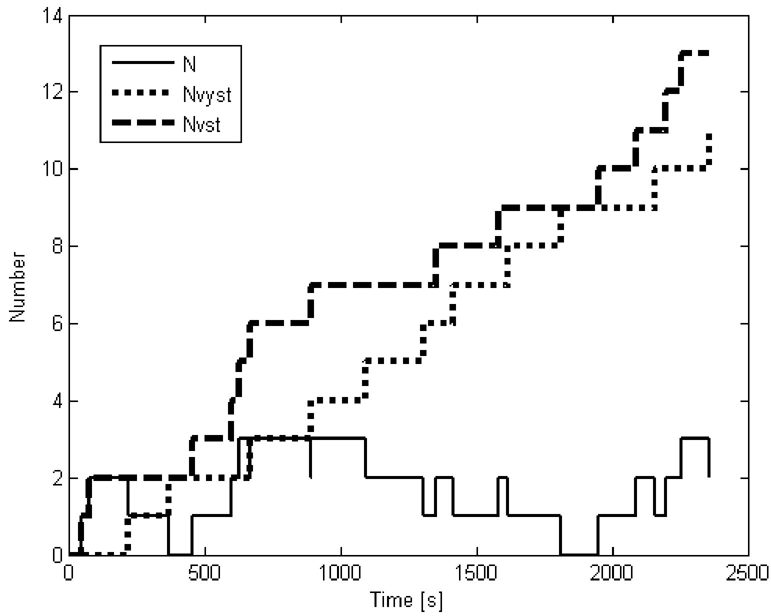

Fig. 2 Graphic Simulation Output

Individual UMPL parts may also be utilized separately. For instance, the EURO UT prefabricated hall with maintained microclimate can be utilized as a temperature-sensitive material storehouse, or possibly as a temporary command post or for lodging purposes in cases of emergency.

According to available information, the UMPL is a unique facility in the conditions of armed forces. Presumably, the UMPL is to be employed in multinational operations under NATO or EU command.

The trial operation made possible to determine types of distribution for UMPL input data, based on which simulation model was developed. The simulation verified estimated capacity parameters stated in the UMPL tactical-technical data; the value of 18 pallet units/h (rounded to whole numbers) lies within the declared interval of 15 to 24 pallet units/h. On the condition of full operation at all 3 UMPL inputs and the use of pallet unit assembly materials from the trial operation, there is a high probability (56.78 %) of the line "congestion". In consequence, work at individual inputs (input1, input2 and input3) would be suspended. With the data and assumptions applied, the constraint is the system proper (from position 11 onwards).

The UMPL tactical-technical data limit the maximum packable pallet unit height to 1,500 mm. The test trial proved that pallet units up to 1,600 mm high can be packed in compliance with ČOS 399 001, Materials Handling in the Field [6].

Due to the model simplicity, further tactical-technical data verification, such as the number of operators, use of different materials for the pallet unit assembly, flaws and failures during UMPL operation etc. were left out of consideration.

Further research shall be concerned with the inclusion of these aspects or other relevant factors, into the mathematical model. This may include:

- application of specific data – types of material and the assortment groups for selected task forces (European Union Battle Group or brigade task force 3000),

- restricted use of individual inputs – simulation made with only one or two inputs,
- setting the number of operators as a parameter and the verification of their busyness under various conditions (in further simulations), as the number of operators is only empirically determined in the UMPL tactical-technical data,
- including error rate (e.g. strap sliding off, wrap misplacement),
- considering time saving resulting from pre-designed load plans or including the working-out time (even for further accompanying documentation) into the total time of the pallet unit assembly,
- including the time required for pallet unit labelling,
- pallet unit assembly with the use of material (containers) of irregular shapes,
- testing the pallet unit assembly having the centre of gravity, for objective reasons, off the ideal centre.

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