SAFETY STORAGE ASSIGNMENT IN AS/RS

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ABSTRACT

Picking time reduction has been the traditional perspective for warehouse optimization. When structural safety is considered, optimization of warehouse operations should be read even in terms of load mass distribution. In many practical cases the static safety of the system is related to mass distribution and barycenter highness, for example when a vehicle hits the structure or even in the extreme case of an earthquake. To investigate the problem a simulation model is developed with AutoMod™ software. The model developed simulates a generalized AS/RS warehouse where the single physical location is managed. To evaluated the performances of the AS/RS a simulation experiment is completed. The aim of the experiment is to investigate the impact of different storage policies on intrinsic structural safety and performances in term of picking time and comparing the results with the variety caused by different factors such as: shuttle speed and warehouse filling rate.

Keywords: AS/RSs, warehouse, seismic safety, mass distribution.

1. INTRODUCTION

Automated Storage and Retrieval Systems (AS/RSs) recorded a significant increase in the last decades, which can be explained by savings in labor costs and floor space, increased reliability and reduced error rates in picking operations (Roodbergen and Vis, 2009).

The use of AS/RSs is widespread in many different industrial contest and some examples can be found even for heavy load applications. For example in a tile manufacture the single load can exceed the weight of 1.000 kg. For all these heavy duty AS/RSs also the aspects about safety are very important. In many practical cases the static safety of the system is related to mass distribution and barycenter highness, for example in the case of a collision between a vehicle and the warehouse structure or, moreover, in the extreme case of an earthquake.

The study of seismic behavior of structure with vertical irregularities in terms of mass, stiffness and strength is mainly focused on building. Past studies indicate that mass irregular distribution has little effect on seismic behavior for building (Khoshnoudian and Mohammadi, 2008), (Magliulo, Ramasco and Realfonzo, 2001) (Al-Alì and Krawinkler, 1998) but these studies were focused on civil building while there are only few examples of studies carried on industrial facilities and, to the best of the authors knowledge, no example at all on AS/RSs facilities.

The reduction of order retrieval time has been the traditional perspective for warehouse optimization only some authors, for example Heragu (2005) used total warehouse cost as objective function. Picking performances are related to the storage assignment policy, which allocates items in convenient locations (Ashayeri and al., 2002) Traditionally we have different strategies to allocate items in an AS/RS. In manufactures AS/RSs can use: a basic “First Free” strategy without any allocation optimization, a ABC strategy where each rack is divided into A, B and C zones organized in columns or in rows or with a more complex clustering strategy. The effectiveness of a strategy usually is evaluated in term of picking time. When safety aspects are considered, optimization of warehouse operations should be read in order to integrate in the evaluation model different aspects as already proposed for “green” factors (Meneghetti, 2010) (Prada and al., 2013).

In 2012 during the earthquake in Emilia region of Italy some AS/RSs facilities suffer serious damage (YouReport, 2012). Till a full comprehension of the influence of mass distribution on AS/RSs will be given, a model able to compare different storage policies even for structural safety aspects could be useful to support management on the tradeoff between time based performances and safety related aspects.

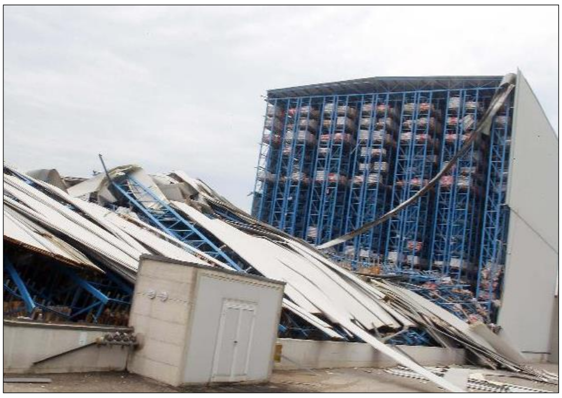

Figure 1: an AS/RS after the earthquake in Emilia – Italy 2013 (ANSA: Italian National Associated Press)

2. PURPOSE

The purpose of the paper is to provide a performance evaluation model for AS/RSs storage policies able to consider also static safety aspects. The work, grounded on a discrete event simulation model, provides a comparison between three different common allocation strategies. The proposed Key Performance Indicators (KPI) will enable practitioners to evaluate AS/RSs allocation strategy considering structural safety aspect too.

3. METHODOLOGY

To investigate the problem a simulation model of the AS/RS is developed according with the standard Bozer and White (1984) model, using AutoMod™ software. SciLab (scilab.org, 2013) open source platform is adopted to generate random initial item allocation set and retrieval orders.

The model developed simulates a single shuttle single command crane AS/RS where the single physical storage location is managed. A full description of possible different AS/RSs configurations is provided in the recent paper of Azzi and al. (2011).

3.1. Simulated system

The simulated system is formed by 2 rack served by a single shuttle crane and each rack is composed by 10 rows and 45 columns for 900 locations. Rack total length is fixed equal to 45 meters and total highness to 20 meters. Simulation model always implements FIFO rule to choose the item to pick.

An initial random items allocation is provided than for each day a picking list is random generated. For each item a random quantity is generated using a "uniform" distributed function. The minimum is always zero and the maximum value is set according with item A/B/C classification. The A/B/C classification is quite different from the classic 80/20 standard, this to better fit real operative conditions. At the end of the day the retrieved quantity is restored in the AS/RS for each item.

3.2. Key Performance Indicators (KPI)

The aim of the experiment is to investigate the impact of different storage policies on intrinsic structural safety and performance in term of picking time. To evaluate the picking performances and the safety related aspect two main KPI are defined:

- KPI1: average time to complete a picking task [sec];
- KPI2: the average barycenter highness [m], KPI2a refers to rack (a) and KPI2b t rack (b).

The aim is to quantify how a safety oriented allocation strategy effects picking time performances.

3.3. Model validation

Simulation model validation is provided to investigate outputs stability under the designed experimental conditions (Davoli et al. 2012). The simulation length has been defined according to the result of mean square pure error (MSPE) analysis and five replications have been used to perform the error analysis; over a number of five replications no significant differences were observed. Simulation stability is reached within simulation period of 10 days.

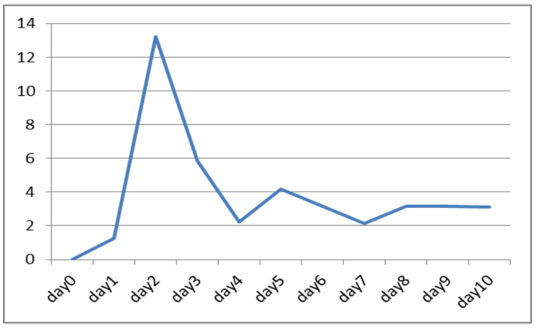

Figure 2: MSPE for KPI1 (task mean time)

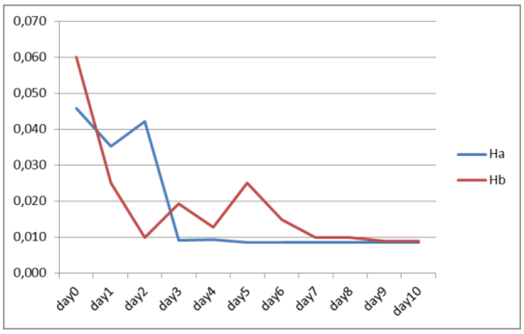

Figure 3: MSPE for KPI2a (Ha) and KPI2b (Hb)

3.4. Design of the Experiment (DOE)

The aim is not to develop a predictive response model but to demonstrate that a simulation approach can be useful and to investigate a case study representative of heavy load AS/RSs. The experiments consider different storage polices, different system fill rate and different speed set of the shuttle.

Table 1: Overview of experimental settings of the four investigated factors

Factors			
Storage Policy	Simple FirstFree	Columns A/B/C	Rows A/B/C
System fill rate	10% free space	30% free space	50% free space
Speed rate (V_h/V_v)	2	1	0.5

- Storage policy, the considered storage polices are: "First Free" where the location search is performed deck by deck; "Columns A/B/C" where the search is performed deck by deck within the columns reserved for the specific class; "Rows A/B/C" where the search is performed column by column within the rows reserved for the specific class.

- System fill rate, the considered initial random allocation for the items are: “Almost full” where the 10% of locations are free, “Half full” where the 30% of locations are free, “Half empty” where the 50% of locations are free.
- Speed rate, three shuttle crane speeds set are considered: V_h=2 m/s, V_v=1 m/s, rate=2; V_h=1.5 m/s, V_v=1.5 m/s, rate =1 and V_h=1 m/s, V_v=2 m/s, rate =0.5.

A full factorial experiment with three levels is used in this paper. Three factors and three levels give $3^3 = 27$ combinations and thus 27 separate experiments were conducted. The three settings for the three factors are shown in Table 1. All the other parameters of the model are fixed at the value are presented described in Table 2.

Table 2: Model Fixed parameters set

Parameters	
N° items	10
“A class” items	2
“A class” demand	40%
“B class” items	3
“B class” demand	30%
“C class” items	5
“C class” demand	30%
Average n° picking list tasks	150

Table 3: Simulation Results

Results					
Storage Policy	Free space [%]	Speed rate	KPI1 [SKU/h]	KPI2a [m]	KPI2b [m]
Columns ABC	10	2	38	9,21	9,11
Columns ABC	30	2	39	7,91	7,65
Columns ABC	50	2	39	5,73	5,66
Columns ABC	10	1	36	9,21	9,11
Columns ABC	30	1	37	7,91	7,65
Columns ABC	50	1	37	5,73	5,66
Columns ABC	10	0,5	65	9,21	9,11
Columns ABC	30	0,5	67	7,91	7,65
Columns ABC	50	0,5	68	5,73	5,66
First Free	10	2	37	9,71	9,73
First Free	30	2	37	7,70	7,50
First Free	50	2	38	5,71	5,69
First Free	10	1	35	9,71	9,73
First Free	30	1	35	7,70	7,50
First Free	50	1	36	5,71	5,69
First Free	10	0,5	63	9,71	9,73
First Free	30	0,5	64	7,70	7,50
First Free	50	0,5	66	5,71	5,69
Rows ABC	10	2	38	9,48	9,45
Rows ABC	30	2	39	9,38	9,25
Rows ABC	50	2	38	9,09	9,11
Rows ABC	10	1	36	9,48	9,45
Rows ABC	30	1	37	9,38	9,25
Rows ABC	50	1	36	9,09	9,11
Rows ABC	10	0,5	64	9,48	9,45
Rows ABC	30	0,5	66	9,38	9,25
Rows ABC	50	0,5	65	9,09	9,11

4. FINDINGS

The results of the experiments are presented in Table 3. KPI1 is presented as Stock keeping Unit (SKU) for hour and KPI2 as meter. KPI2b, referred to rack b, is always lower than KPI2a, that because logic searching function always begin from rack b, in any case the differences are always negligible.

4.1. ANOVA TEST

The design and analysis of experiments have been conducted using the open source software R (r-project.org, 2013). The ANOVA tables for all KPI are presented in Figure 3, 4 and 5. Pr-values emphasized with (*) indicate variables significant on a better than 0.05 level. The ANOVA test reveals that the considered factors have different impact on KPI1and KPI2, while relevant factors have the same effects on KPI2a and KPI2b.

```
Response: KPI1
                        Df Sum Sq Mean Sq F value    Pr(>F)
StoragePolicy            1    6.1     6.1  0.0207 0.8870852
FillRate                 1   27.6    27.6  0.0931 0.7634214
SpeedRate                1 4982.6  4982.6 16.8297 0.0005537 ***
StoragePolicy:FillRate   1    3.3     3.3  0.0110 0.9173835
StoragePolicy:SpeedRate  1    0.0     0.0  0.0000 0.9984568
FillRate:SpeedRate       1    0.0     0.0  0.0001 0.9931653
Residuals               20 5921.2   296.1
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
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Figure 4: Anova test result for KPI1

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Response: KPI2a
                        Df  Sum Sq Mean Sq F value    Pr(>F)
StoragePolicy            1 13.0151 13.0151  31.868 1.590e-05 ***
FillRate                 1 30.9616 30.9616  75.810 3.076e-08 ***
SpeedRate                1  0.0000  0.0000   0.000 1.0000000
StoragePolicy:FillRate   1  7.2111  7.2111  17.657 0.0004387 ***
StoragePolicy:SpeedRate  1  0.0000  0.0000   0.000 1.0000000
FillRate:SpeedRate       1  0.0000  0.0000   0.000 1.0000000
Residuals               20  8.1682  0.4084
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Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
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Figure 5: Anova test result for KPI2a

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Response: KPI2b
                        Df  Sum Sq Mean Sq F value    Pr(>F)
StoragePolicy            1 14.4978 14.4978  35.803 7.509e-06 ***
FillRate                 1 30.7082 30.7082  75.836 3.067e-08 ***
SpeedRate                1  0.0000  0.0000   0.000 1.0000000
StoragePolicy:FillRate   1  7.2312  7.2312  17.858 0.0004148 ***
StoragePolicy:SpeedRate  1  0.0000  0.0000   0.000 1.0000000
FillRate:SpeedRate       1  0.0000  0.0000   0.000 1.0000000
Residuals               20  8.0985  0.4049
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Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Figure 6: Anova test result for KPI2b

4.2. DISCUSSION

The results indicate that, for the studied system, the key factor to maximize the AS/RS throughput is the rate between horizontal and vertical shuttle speed, or better shuttle speed itself is the key factors. Despite to the fact that the “Columns ABC” policy always guarantees the best throughput, the chosen storage policy, traditionally known as a key factor, in this specific contest is almost irrelevant, and this is clearly supported by the ANOVA test results.

The results indicate that barycenter highness is strongly related to warehouse fill rate and to storage policy. If the firs result is quite obvious the second result is relevant, moreover the ANOVA test reveals the existence of a combined effect between fill rate and storage policy. “Rows ABC” policy in particular presents a higher barycenter position even when the fill rate is 50%. “Column ABC” and “First Free” storage policies both present almost the same result for what concern barycenter highness. But the two storage polices generate different load distribution even though the barycenter highness s almost the same, this is a limit of the chosen KPI2 used to quantify “mass irregular distribution”.

5. CONCLUSIONS

The work shows that a simulation model is useful to investigate mass distribution in an AS/RS. Despite to the fact that there is no deeper study that investigate the relationship between mass irregular distribution and structural safety of AS/RSs, the recent earthquake, occurred in Emilia, Italy, suggest to consider this aspect while choosing the storage policy, especially for heavy duty AS/RSs. Moreover, the system studied in this paper reveals that in specific conditions of physical dimension, shuttle speed and A/B/C classes features adopting a more conservative storage policy doesn’t reduce significantly the AS/RS potential.

6. FURTHER WORKS

The present paper shows the limits related to the use of simply barycenter highness to quantify mass distribution. More sophisticated KPIs should be developed to measure irregularities in mass distribution, this activity should be carried on together with seismic AS/RSs behavior studies.

A statistical analysis about heavy duty AS/RSs should be carried on to investigate the real working condition of these industrial facilities especially about: system fill rate, shuttle speed, A/B/C classes features and adopted storage policies. The result of this study will be useful to understand if the adoption of a conservative, structural safety oriented, storage policy will reduce significantly AS/RSs throughput.

REFERENCES

Al-Alì, A.A.K., Krawinkler, H., 1998. *Effects of Vertical Irregularities on Seismic Behavior of Building Structure*, Report No. 130. Ed. The John A. Blume Earthquake Engineering Center at Stanford University CA (USA).

Ashayeri, J., Heuts, R. M., Valkenburg, M. W. T., Veraart, H. C., Wilhelm, M. R., 2002. *A geometrical approach to computing expected cycle times for zonebased storage layouts in AS/RS.* International Journal of Production Research, 40(17), 4467–4483.

Azzi A., Battini D., Faccio M., Persona A., Sgarbossa F., 2011. *Innovative travel time model for dual-shuttle automated storage/retrieval systems*. Computers & Industrial Engineering, 61, 600–607.

Bozer, Y. A., White, J. A., 1984. *Travel-time models for automated storage/retrieval systems*. IIE Transactions, 16(4), 329–338.

Davoli, G. Nielsen, P., Pattarozzi, G. Melloni, R., 2012. “Practical considerations about error analysis for discrete event simulations model.” *Proceedings of the International Conference on Advances in Production Management Systems*, September 24-26, (Rhodes – Greece).

Khoshnoudian, F., Mohammadi S.A., 2008. Seismic response evaluation of irregular high rise strustures by modal pushover analysis, *Proceedings of the 14th World Conference on Earthquake Engineering*, October 12-17, Beijing (China).

Heragu, S. S., Du, L., Mantel, R. J., & Schuur, P. C., 2005. *Mathematical model for warehouse design and product allocation*. International Journal of Production Research, 43(2), 327–338.

Magliulo, G., Ramasco, R., Realfonzo, R., 2001. Sul comportamento sismico di telai piani in c.a. caratterizzati da irregolarità in elevazione. *Proceedings of the 10° Convegno Nazionale “L’ingegneria Sismica in Italia”*, September 9-13 (Potenza-Matera – Italy) 2001

Meneghetti, A., 2010. Sustainable storage assignment is AS/RSs, *Proceedings of the International Conference APMS 2010,* October 11-13, Cernobbio (Como – Italy);

Prada, L., Garcia, J., Calderon, A., Garcia, J.D., Carretero, J., 2013. *A novel black-box simulation model methodology for predicting performance and energy consumption in commodity storage devices.* Simulation Modelling Practice and Theory, 34, 48–63.

Roodbergen, K.J., Vis, I.F.A., 2009. A survey of literature on automated storage and retrieval systems. *European Journal of Operational Research*, 194, 343-362.

YouReport, 2012. Available from: http://www.youreporternews.it/2012/terremoto-crolla-capannone-ceramica-a-santagostino/ [accessed 15 July 2013].

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