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| Table 1 KPIs Associated with MES | | |
| Worker productivity, | Provides information about the ratio of job-related working hours of employees in relation to the total attendance time of the employee. | Worker Productivity = WOT/TAT |
| Allocation degree, | The allocation degree is the relationship of the holding time of all jobs involved to the entire cycle time of the orders. The allocation degree is an index for the process density and thus for the height of the rotating resources in the manufacturing (work in process, WIP inventory) as well as maintenance and downtimes. To high WIP of resources robs liquidity, causes subsequent costs by the downtimes (container, transport, search expenditure, etc.) and is extending the cycle time. | Allocation degree = BT/TPT |
| Throughput, | The throughput is an index for the performance of a process, i.e. the quantity per unit time is produced. This performance indicator is an important index for the efficiency in production. | Throughput = PQ/TPT |
| Allocation efficiency, | The allocation efficiency is the ratio between the real allocation time of a machine and planned time for allocating the machine | Allocation efficiency = BT/PBT |
| Efficiency, | The efficiency is the portion of the main usage time of the entire allocation time, thus it is a measure for the productivity of the machine. Since only the operating time is value-adding and is remunerated by the market, for an enterprise it must be the goal to increase this portion drastically | Efficiency = PDT/BT |
| OEE Index, | Overall Equipment Effectiveness (OEE) is a measure for the efficiency of machines and/or plants, manufacturing cells with several machines or an entire assembly line. The OEE Index forms the basis for improvements by better production information, identification of production losses, and improvement of the product quality by optimized processes.  The OEE Index represents the used availability, the effectiveness of the production unit, and their quality rate summarized in a characteristic number. | OEE Index = Availability \* Effectiveness \* Quality rate |
| NEE Index, | The NEE Index gives hints to losses by plant stop, cycle time losses and losses due to defective and to-be-reworked products | NEE Index = PCT/PBT \* Effectiveness \* Quality rate |
| Availability, | The availability indicates, how strongly the capacity of the machine for the worth-drawing functions related to the planned availability is used. | = PDT/PBT |
| Effectiveness, | The effectiveness is the measure for the power of a process. The relationship of the target cycle to the actual cycle is represented. The effectiveness is a characteristic number, which may be calculated and displayed in short periodic distances at run time of a machine. | Effectiveness = PTU \* PQ / PDT |
| Quality Rate, | The quality rate is the relationship of the proper quantity to the produced quantity. | Quality Rate = GQ / PQ |
| Preparation degree, | The preparation degree is an index for the preparation portion related to the operating time at a machine. The larger the value becomes, the higher the preparation part of the time that was announced with the production order at the machine. For an enterprise a high preparation degree means a consumption of valuable time, which is not worth drawing in the actual sense. | Preparation Degree = ESUT/BRZ |
| Technical Usage Level, | The technical usage level is the efficiency of a machine. It is the relationship between the main usage period and the main usage period including the fault caused interruptions. | Technical Usage Level = PDT / (PDT + DeT) |
| Wastage Degree, | Border definition for wastage and examination of the compliance. The wastage degree shall take into account process-conditioned wastage on one hand and on the other hand it should stay below one hundred percent. | Wastage Degree = SQ / PSQ |
| First Pass Yield (FPY), | The FPY is a characteristic number for the direct process quality regarding work place and product. If the result of the characteristic number becomes larger, the so-called "yield" increases, error costs and material wastage are avoided, the yield quantities are increased. | FPY = GP / PT |
| Wastage Ratio, | The wastage ratio gives the percentage portion of the entire production, which is wastage. | Wastage Ratio = SQ / PQ |
| Reworking Ratio, | The reworking ratio gives the proportional portion of entire production which is reworking. | Reworking Ratio = RQ / PQ |
| Fall off Rate | This indicator is applied with concatenated processes, on the basis of a mother product (e.g. basis building group or motherboard) which is produced in the first manufacturing step and leads to further wastages in the context of the following manufacturing steps. The mother products can be serialized in the first manufacturing step. The characteristic number has an influence on the planning quality (planned wastage) and on the production quality per manufacturing step as well as the material wastage. This characteristic number indicates, how big the wastage ratio is in relation to the produced amount of the first manufacturing step. | Fall off Rate = SQ / PQ of the first manufacturing step |
| Machine Capability Index (Cm), | The machine capability index shows the ability of a machine or a work mechanism to produce the demanded quality. The evaluation should take place if possible under exclusion of further process influences. Application takes place mainly with the approval from plants/machines/products | Cm = (ULV - LLV ) / (6 \* s) |
| Critical Machine Capability Index (Cmk), | The critical machine capability index shows the ability of a machine or a work mechanism to produce the demanded quality. The evaluation should take place if possible under exclusion of further process influences. Application takes place mainly with the approval from plants/machines/products | Cmko = (ULV - xqq) / (3 \* s) ; Cmku = (Xqq - LLV) / (3 \* s) |
| Process Capability Index (Cp), | The process capability shall prove as early as possible with statistic methods that the manufacturing process can surely manufacture the products with the demanded quality. The process capability index Cp designates the relationship between the dispersion of a process and the specification borders. The range between the specification borders (tolerance width) is compared with the 6-times process dispersion. A process is usually called capable if the process capability index is > 1,33. | Cp = (ULV - LLV) / (6 \* ) |
| Critical Process Capability Index (Cpk), | The process capability shall prove as early as possible with statistic methods that the manufacturing process can surely manufacture the products with the demanded quality.  With the critical process capability Cpk additionally the average value is considered, as the smallest distance between average value and specification border is compared with the triple dispersion.  A process is usually called capable if the critical process capability index is > 1,33. | Cpko = (ULV - xqq) / (3 \* ) ; Cpku = (xqq - LLV) / (3 \* ) |
| Environmental compatibility KPIs, | | |
| Emission ratio, | The energy balance of the entire climate system is affected by changes in the atmospheric abundance of greenhouse gases. The most important anthropogenic greenhouse gas is carbon dioxide since CO2 comprises 80 % of the total greenhouse gases. The concentration of carbon dioxide has increased from a pre-industrial value of 280 ppm to 379 ppm in 2005. This has resulted in a rise in global temperature of 0.76 °C and therefore a rise in sea levels of 0.17 m during the 20th century. Therefore the recommendation is that fossil CO2 emissions are monitored as the total amount produced within the system borders earlier defined. | Emission ratio = (CO2energy + CO2transported goods + CO2travel + CO2internal) / VA |
| Energy ratio, | The energy sector contributes a large amount of the pollution of greenhouse gases. Nuclear energy production partly effects the immediate surrounding environment and furthermost has an effect during mining of nuclear fuel. The final storage of used radioactive material has an impact on the environment under at least 100 000 years. Even renewable energy has an impact on the close surrounding environment as land is taken in use by the constructions. The measurement of CO2 will be an initiative for lowering the dependence of fossil energy and therefore total energy consumption should be measured since lowered total energy consumption is desirable. | Energy ratio = (energy bought + energy internally produced) / VA |
| Ratio of used material | Manufacturing that reduces the amount of used materials in the process will lessen its impact on the environment. A study indicates that if material reduction is fully utilized this will result in lowered carbon dioxide emission from transportation and energy production. | Ratio of used material = total amount of material used / VA |
| Harmful substances, | Successful reduction of harmful substances in production will lead to lowered danger of hazardous accidents and therefore lowered risk of cost associated with sanitation for the producer and the society. The global restoration of environmental devastation has been estimated to $125 billion. Production of harmful substances in the European Union has unfortunately increased from 259 million tons in1996 to 317 million tons in 2007. | Harmful substances = total used amount of harmful substances in tons / VA |
| Hazardous waste, | The total amount of hazardous waste in the EU was 84.4 million tons in 2006, an increase by 14 % from 2004. In the US hazardous waste has increased with 54.7 % from 2003 to 2007. The manufacturing industry is responsible for the majority of total hazardous waste. Agenda 21 suggest several actions for governments in order to strengthen the international capacity of handling hazardous waste such as invest in R&D associated with waste management, increase information and education on the subject, improving waste handling infrastructure, establish legal frameworks etc. Actions incurring an estimated global cost of 18.5 billion dollars yearly. As the amount of hazardous waste is increasing and incurs great costs for the society, the authors find this indicator highly relevant. | Ratio of hazardous waste= total amount of hazardous waste/ VA |
| Comprehensive Energy Consumption, | Comprehensive Energy Consumption is the ratio between all the energy consumed in a production cycle and produced quantity.  e: unit energy consumption of statistical object, standard quantity / ton  E: comprehensive energy consumption, standard quantity  Mi: actual consumption of certain kind of energy, ton (kilowatt hour)  Ri: conversion coefficient of certain kind of energy, standard quantity / ton  Q: algebraic sum of effective energy exchanges with environment, standard quantity  PQ is expressed in tons | e = E/PQ =（∑Mi\*Ri + Q）/ PQ |
| KPIs for inventory handling and management, | | |
| Inventory turns | The Inventory Turns is defended as the ratio of the throughput (TH) to average inventory. It is commonly used to measure the efficiency of inventory, and represents the average number of times the inventory stock is replenished or turned over. | Inventory Turns = Throughput / average inventory |
| KPIs for input-output (quality of manufacturing process), | | |
| Finished Goods Rate | The Finished Goods Rate is the ratio of the good quantity produced (GQ) to the consumed material. | Finished Goods Rate = GQ / consumed material |
| Integrated Goods Rate | The integrated goods rate is the relationship of the proper quantity to the consumed material. | Finished Goods Rate = (Integrated Good quantity )/ (  consumed material) |
| Production Lost Rate | The production lost rate is the relationship of the quantity of the lost during production to the consumed material. | Production Lost Rate = production lost / consumed material |
| Storage and Transportation Lost Rate | The storage and transportation lost rate is the relationship of the quantity of the lost during storage and transportation to the consumed material. | Storage and Transportation Lost Rate = (storage and transportation )/(lost consumed material) |
| Other Lost Rate | The other lost rate evaluates the lost that is not during production, storage, or transportation. | Other Lost Rate = other lost / consumed material |
| KPIs of Load Rate | | |
| Equipment Load Rate | Provides information about the ratio of produced quantity (PQ) in relation to the maximum equipment production capacity. It is an indicator to reflect the production state of equipment and production efficiency. It helps to reflect the technical performance and utilization of equipments and by researching the usage of equipment | Equipment Load Rate = PQ / maximum equipment production capacity |

### DNC

There are many areas in industry that could benefit from new standards. Foremost, is DNC, which is a common manufacturing term for either Direct numerical control or distributed numerical control. In either case, DNC provides service for networking CNC machine tools and allows upload/downloads/execution/delete of programs on CNCs. Unfortunately, there is no single universal standard, so each CNC vendor and each CNC integrator must account for each vendor-proprietary solution. This lack of a downloading standard is a headache but not a show stopper so that integration vendors accept the dichotomy and the CNC vendors can continue to sell proprietary CNC networked downloading solutions.



In our work, we developed a prototype DNC that could use the MTConnect "Read-read" paradigm for transmittal/acknowledgements of commands and files. The proposed system was validated against a Fanuc Focas2 DNC functionality and MTConnect part identification technical activity group.