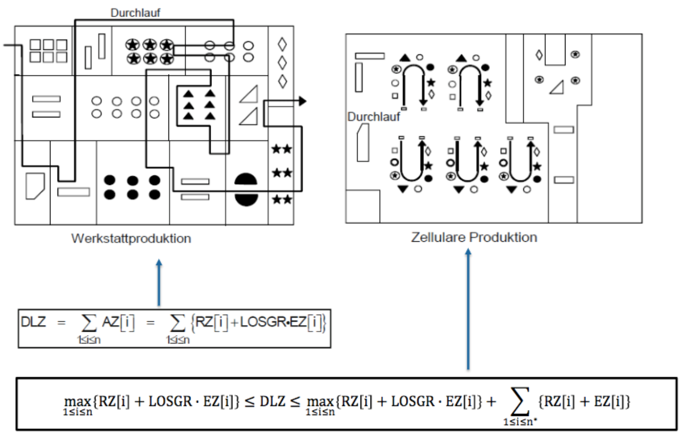
Formelsammlung Lean/ Rechnungen

Begriff Englisch	Begriff Deutsch	Formel
	Übungsserie 1 KPI: Key Performance Indicators	
Scrap Factor %	Ausschussfaktor	$\frac{Anz.\, zurückgewiesene\ Teile}{Anz.\, Teile\ gesamt}$
Yield Factor %	Gutfaktor	1 – Scrap Factor (Bsp.: Wenn Scrap Factor 2% dann Yield Factor 98%)
Work center efficiency %	Arbeitsplatzeffizienz	$\frac{Anz.\, produzierte\ Teile}{Anz.\, geplante\ Teile\ (Normalfall)}$
Capacity utilization %	Kapazitätsausnutzung	$\frac{Aktuell\ produzierte\ Stück}{Theoretische\ Kapazität}$
Inventory turnover	Lagerumschlag	$\frac{COGS}{Durchschnittliches\ Inventar}$
Fill rate/ service ratio %	Leistungsverhältnis	$\frac{Anz.\, Teile\ geliefert}{Anz.\, Teile\ bestellt}$
Delivery reliability rate %	Lieferzuverlässigkeitsrate	$\frac{Effektiv\ gelieferte\ Teile}{Anzahl\ versprochener\ Teile}$
Value-added rate of lead time %	Mehrwertrate von Durchlaufzeit	$\frac{Zeit\ wertschöpfende\ Arbeit}{Zeit\ gesamter\ Prozess}$
Bid proposal success rate %	Erfolgsquote Angebote	$\frac{Number\ of\ bid\ position\ proposed}{Number\ of\ customer\ requests\ for\ quotations}$
Order success rate %	Erlofgsrate Bestellungen	$\frac{Number\ of\ order\ positions}{Number\ of\ bid\ positions}$
Cash-to-cash cycle time	Geld-zu-Geld Zykluszeit	CCC = DIO + DSO – DPO = Days Inventory Outstanding / Receivable Days + Days Sales Outstanding – Days Payable Outstanding
Return on Assets (RONA) %	Kapitalrendite	$\frac{Net\ income}{fixed\ assets + Net\ working\ capital}$ *Net working capital = Current assets – current liability*

Productivity (I) Units per time	Produktivität	$\frac{Teile\ produziert}{Zeit}$
Productivity (II) Each h employe produce x $	Produktivität	$\frac{Total\ sales}{Total\ hours\ worked}$
	Übungsserie 2 JIT: Just-In-Time	
Operationtime	Arbeitsgangzeit	$Einzelzeit * Losgrösse + Rüstzeit$
Operationtime/Unit	Arbeitsgangzeit/Einheit	$\frac{Einzelzeit * Losgrösse + Rüstzeit}{Losgrösse}$
	Durchlaufszeit	Sum(Operationtimes)
Cell driver	Zelltreiber	max{Rz + Ez* Losgrösse} -> Längster aller Arbeitsschritte
	Zellularproduktion Max Durchlaufzeit	Cell driver + Sum{Rz + Ez} ohne Rz+Ez von Cell driver 
	Übungsserie 3 Forecast	
Weighted moving averrage		Example 0.1*WEEK4 + 0.2 * WEEK3 + ... + 0.1 * CURRENT WEEK = RESULT
Simple 3 Month moving average		

Month	Actual	Moving Average
January	115	
February	140	
March	141	
April	168	132.00
May	158	149.67
June	183	155.67
July	144	169.67
August	135	161.67
September	145	154.00

<table>
<tr>
<td>Exponential Smoothing</td>
<td></td>
<td>
$F_t = F_{t-1} + \alpha(A_{t-1} - F_{t-1})$
where
F_t = The forecast for period t
F_{t-1} = The forecast for the previous period
A_{t-1} = The actual demand or sales from the previous period
α = Smoothing constant

Example:
Saturday Hotel Occupancy (α =0.5)
<table>
<tr><th>Period
t</th><th>Occupancy
A_t</th><th>Forecast
F_t</th><th>Forecast Error
$|A_t - F_t|$</th></tr>
<tr><td>1</td><td>79</td><td>---</td><td></td></tr>
<tr><td>2</td><td>84</td><td>79.00</td><td>5</td></tr>
<tr><td>3</td><td>83</td><td>79+0.5(84-79)=81.50 or 82</td><td>1</td></tr>
<tr><td>4</td><td>81</td><td>81.5+0.5(83-81.5)=82.25 or 82</td><td>1</td></tr>
<tr><td>5</td><td>98</td><td>82.25+0.5(81-82.25)=81.63 or 82</td><td>16</td></tr>
<tr><td>6</td><td>100</td><td>81.63+0.5(98-81.63)= 89.81 or 90</td><td>10</td></tr>
<tr><td></td><td></td><td></td><td>MAD =33/5= 6.6</td></tr>
</table>

Forecast Error (Mean Absolute Deviation) = $\Sigma|A_t - F_t| / n$
The first actual value is used as the forecast for period 2
</td>
</tr>
<tr>
<td>Exponential Smoothing with Trend</td>
<td>T_{t-1} = The exponentially smoothed trend for the prior period</td>
<td>
$F_t = FIT_{t-1} + \alpha(A_{t-1} - FIT_{t-1})$
$T_t = T_{t-1} + \delta(F_t - FIT_{t-1})$
$FIT_t = F_t + T_t$
where
F_t = The exponentially smoothed forecast that does not include trend for period t
T_t = The exponentially smoothed trend for period t
FIT_t = The forecast including trend for period t
FIT_{t-1} = The forecast including trend made for the prior period
A_{t-1} = The actual demand for the prior period
α = Smoothing constant
δ = Smoothing constant

Example:
$FIT_{t-1} = 110$ units (Forecasted Demand for that period)
$A_{t-1} = 115$ units (Actual Demand for past period)
T_{t-1} = smoothing constant for the Forecast without the trend = 0.2
δ = smoothing constant for the trend = 0.3
$T_{t-1} = 10$

$F_t = FIT_{t-1} + \alpha(A_{t-1} - FIT_{t-1}) = 110 + 0.2(115 - 110) = 111$
$T_t = T_{t-1} + \delta(F_t - FIT_{t-1}) = 10 + 0.3(111 - 110) = 10.3$
$FIT_t = F_t + T_t = 111 + 10.3 = 121.3$
</td>
</tr>
</table>

MAD MSE MAPE	Rechenbeispiel: MAD = (|x|+|y|+|z|)/3 MSE = $(x^2 + -y^2 + z^2)/2$ MAPE = MAD+ 1/AVG*100 *100 -> %	see below

- **Error = Actual – Forecast**
- If errors fall beyond acceptable bounds, corrective action may be necessary

$$\text{MAD} = \frac{\sum |\text{Actual}_t - \text{Forecast}_t|}{n}$$

Mean Absolute Deviation (MAD) weights all errors evenly

$$\text{MSE} = \frac{\sum (\text{Actual}_t - \text{Forecast}_t)^2}{n-1}$$

Mean Square Error (MSE) weights errors according to their squared values

$$\text{MAPE} = \frac{\sum |\text{Actual}_t - \text{Forecast}_t|}{n \times (\text{Average Demand})} \times 100$$

Mean Absolute Percentage Error (MAPE) weights errors according to relative error

Example:

Period	Actual (A)	Forecast (F)	(A-F) Error	|Error|	Error²	
1	107	110	-3	3	9	
2	125	121	4	4	16	
3	115	112	3	3	9	
4	118	120	-2	2	4	
5	108	109	-1	1	1	
AVG(A)	114.6		Sum	13	39	
				n = 5	*n-1* = 4	
				MAD	MSE	MAPE = MAD / AVG(A)
				= 2.6	= 9.75	= 2.6 / 114.6= 2.27%

Übungsserie 4

Inventory Management

Replensihment order	Nachschubauftrag	$\frac{produzierte\ Einheiten\ /\ Jahr}{Nachschubaufträge\ /\ Jahr}$
Andler-Formel EOQ Optimal order quantity		see below

$$Q^* = \sqrt{\frac{2AD}{pC}}$$

D = Yearly Demand (unit / year)
C = Purchasing price (CHF / unit)
Q = Order Quantity (unit)
A = Fixed ordering (setup) cost per Order (CHF)
p = Inventory interest cost (%)

$$T^* = \frac{Q^*}{D} = \sqrt{\frac{2A}{DpC}} \qquad n^* = \frac{D}{Q^*} = \sqrt{\frac{DpC}{2A}} \qquad Y^* = \sqrt{2ADpC} + CD$$

T*: Reorder interval length (Eindeckungsdauer)
n*: Ordering frequency, number of orders per time
Y*: Optimal Cost (carrying cost = ordering cost)

Total cost = $Y(Q) = CD + pC\frac{Q}{2} + A\frac{D}{Q}$

- CD → Net purchasing cost (Einkaufskosten)
- $pC\frac{Q}{2}$ → Carrying cost (Lagerkosten)
- $A\frac{D}{Q}$ → Setup and Ordering cost (Bestellkosten)

<table>
<tr>
<td>Probability of not being sold</td>
<td>Wahrscheinlichkeit nicht zu verkaufende Güter</td>
<td>

$$P(D \leq Q^*) = \frac{C_U}{C_O + C_U}$$

$$C_u: under - stocking\ unit\ cost = r - c$$
$$C_o: over - stocking\ unit\ cost = c - b$$

c = Purchasing price (CHF/unit)
r = Selling price (CHF/unit)
b = Salvage value (CHF/unit)
Q = Order Quantity
D = Demand (units, random variable)
Definition: r > c > b
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Service Level	Safety factor k
50%	0
60%	0.385
80%	0.842
90%	1.282
95%	1.645
99%	2.326
99.9%	3.090

</td>
<td>

$$Q^* = \mu + k^* \sigma$$

N(μ, σ) bsp. N(1000, 3000)
</td>
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<tr>
<td>R, Q parameters</td>
<td></td>
<td>

Rule: Order Q whenever inventory level reaches R

- Set *Q* as the EOQ solution
- Set *R* as the newsboy solution

1. $P(D < R) = \alpha$ or demand forecast during the lead time + safety stock
2. Where α is the desired service level (e.g. 95%)

Example: Suppose a retailer procures Cola from its supplier at 0.5 CHF each (purchase + shipment cost); in addition each order costs 100 CHF order cost. If weekly demand is N(500,80) and an inventory holding cost of 0.1 CHF per week. Delivery time is 2 weeks.

If the manager applies continuous review system, please calculate the values of *Q* and *R* for a 95% service level.

$Q^* = \sqrt{\frac{2AD}{h}} = \sqrt{\frac{2*100CHF*500\ unit}{0.1\ CHF/unit}}$ = 1000 units

$R = d*L + k*\delta_L = 500\frac{units}{week} * 2weeks + 1.64*\sqrt{2}*80units = 1186$ units
</td>
</tr>
<tr>
<td>S, T parameters</td>
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Rule: Order back to *S* every *T* time units

- Set *T* as the EOQ solution divided by the demand rate
- Set *S* as the newsboy solution

1. $P(DLR < S) = \alpha$ (Service Level, eg. 95%)
2. or demand forecast during the lead time d and review period T + safety stock (DLR)

Example: Suppose a retailer procures Cola from its supplier at 0.5 CHF each (purchase + shipment cost); in addition each order costs 100 CHF order cost. If weekly demand is N(500,80) and an inventory holding cost of 0.1 CHF. Delivery time is 2 weeks.

If the manager applies continuous review system, please calculate the values of *T* and *S* for a 95% service level.

$T^* = \frac{Q^*}{D} = \sqrt{\frac{2A}{Dh}}$ = 2 weeks,

$S = d(T+L) + k\sigma_{T+L}$ = 500 units/week * 4 weeks+ 1.64*$\sqrt{4} * 80\ units$= 2263 units
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<td>The ABC Classification</td>
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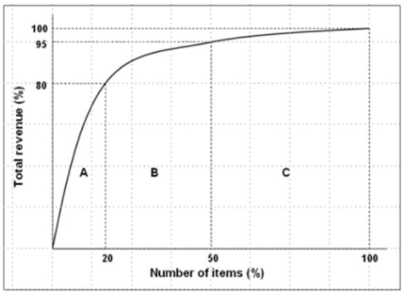
Pareto Chart



A class is composed of 20% of the items which account for 80% of the total turnover

B class, is made of about 30% of the items, which comprise approximately 15% of total turnover

C class, is the remaining items, which make up a large part of the product range, only account for approximately 5% of total turnover
</td>
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</table>

Reorder qualits & order up to level	anhand eines Bsp. A reorder.. B order up..	(see below)

Item	A	B
Daily demand	N(100,20)	N(50,10)
Unit item cost (*C*)	CHF 10	CHF 2
Holding cost (*p*)	20%	20%
Order cost (*A*)	CHF 150	CHF 25
Lead time (*L*)	4 weeks	1 week
Target service level	95%	95%

a) Reorder quantity: $Q^* = \sqrt{\frac{2AD}{h}} = \sqrt{\frac{2*150CHF*100\ units/day*365days}{2\ CHF/unit}} = 2339$ units

$\sigma_L = \sqrt{\sum_{i=1}^{L} \sigma^2} = \sqrt{7*4*20units*20\ units} = 106\ units$

Reorder point: $R = d*L + k*\sigma_L = 100\ units/day*4*7days + 1.64*106\ units = 2974$ units

b) $Q^* = \sqrt{\frac{2AD}{h}} = \sqrt{\frac{2*25\ CHF*50\frac{units}{day}*365days}{0.4}} = 1510$ units

Review period: $T^* = \frac{Q^*}{d} = 30$ days

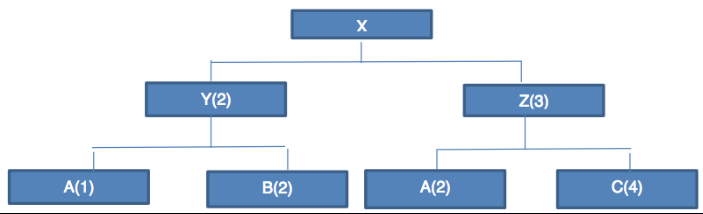
Order-up-to level: $\sigma_{T+L} = \sqrt{(T+L)\sigma^2} = \sqrt{(30+7)}*10\ units = 60.82\ units$

$S = d(T+L) + k\sigma_{T+L} = 50\frac{units}{day}*(30+7)days + 1.64*60.82\ units = 3430$ units

Übungsserie 5

Material Management

Product Structure Tree



Songle level part list

M
- N(2)
- P(3)

N
- R(2)
- S(4)

R
- S(1)
- T(3)

P
- T(2)
- U(4)

Indented part list

M
- N(2)
  - R(2)
    - S(1)
    - T(3)
  - S(4)
- P(3)
  - T(2)
  - U(4)

MRP records

Time-Phasing: find a schedule for when orders needed to be released (due to lead time)

Item A

Item A		Week 4	5	6	7	8	9
L = 2 weeks	Gross requirements						1250
On hand = 50	Scheduled receipts						
Safety Stock = 0	Projected available balance	50	50	50	50	50	0
Order qty = lot-for-lot	Net requirements						1200
	Planned order receipts						1200
	Planned order releases				1200		

Lead Time = 2 weeks

Item B -> Same process for item B

Item B		Week 4	5	6	7	8	9
L = 2 weeks	Gross requirements						470
On hand = 60	Scheduled receipts		10				
Safety Stock = 0	Projected available balance	60	60	70	70	70	0
Order qty = lot-for-lot	Net requirements						400
	Planned order receipts						400
	Planned order releases				400		

Planned order release for items A and B, for every item A and item B, 1 item C is required

Item C		Week 4	5	6	7	8	9
L = 1 week	Gross requirements				1600		
On hand = 40	Scheduled receipts						
Safety Stock = 5	Projected available balance	35	35	35	435	435	435
Order qty = 2000	Net requirements				1565		
	Planned order receipts				2000		
	Planned order releases			2000			

Each item C requires 2 items D

Planned order release for items A, one item A requires 1 item D

Item D -> Same process for item D

Item D		Week 4	5	6	7	8	9
L = 1 week	Gross requirements			4000	1200		270
On hand = 200	Scheduled receipts	100					
Safety Stock = 20	Projected available balance	280	280	1280	80	80	4810
Order qty = 5000	Net requirements			3720			190
	Planned order receipts			5000			5000
	Planned order releases		5000			5000	

4 lot-sizing-rules

Lot-for-lot

Week	Net Requirement	Production Quantity	Ending Inventory	Carrying Cost	Setup Cost	Total Cost
1	105	105	0	0	100	100
2	80	80	0	0	100	200
3	130	130	0	0	100	300
4	50	50	0	0	100	400
5	0	0	0	0	100	500
6	200	200	0	0	100	600
7	125	125	0	0	100	700
8	100	100	0	0	100	800

D= Annual demand= (105 units +80 units +130 units +50 units +0 units +200 units +125 units +100 units)/8 weeks × 52 weeks=5135 units

H=Annual holding cost = 0.208 × 25CHF= 5.2 CHF

A= Setup cost= 100 CHF

$\text{EOQ} = \sqrt{\frac{2AD}{H}}$=444 units

In computing holding costs per week, divide H by 52. Weekly holding cost is 0.1 CHF per unit.

EOQ

Week	Net Requirement	Production Quantity	Ending Inventory	Carrying Cost	Setup Cost	Total Cost
1	105	444	339	33.90	100.00	133.90
2	80	0	259	25.90	0.00	159.80
3	130	0	129	12.90	0.00	172.70
4	50	0	79	7.90	0.00	180.60
5	0	0	79	7.90	0.00	188.50
6	200	444	323	32.30	100.00	320.80
7	125	0	198	19.80	0.00	340.60
8	100	0	98	9.80	0.00	350.40

Part-period planning

Weeks	Net Requirement	Quantity Ordered	Carrying Cost	Setup Cost	Total Cost
1	105	105	0.00	100.00	100.00
1-2	80	185	8.00	100.00	108.00
1-3	130	315	34.00	100.00	134.00
1-4	50	365	49.00	100.00	149.00
1-5	0	365	49.00	100.00	149.00
1-6	**200**	**565**	**149.00**	**100.00**	**249.00**
6	200	200	0	100.00	100.00
6-7	125	325	12.50	100.00	394.00
6-8	100	425	32.50	100.00	110.00

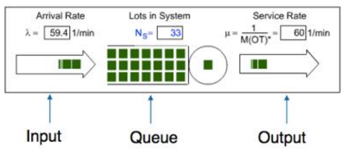
Fixed Order Periods

Week	Net Requirement	Production Quantity	Ending Inventory	Carrying Cost	Setup Cost	Total Cost
1	105	365	260	26.00	100.00	126.00
2	80	0	180	44.00	0.00	160.00
3	130	0	50	49.00	0.00	209.00
4	50	0	0	49.00	0.00	29.00
5	0	0	0	49.00	0.00	249.00
6	200	425	225	22.50	100.00	122.50
7	125	0	100	10.00	0.00	132.50
8	100	0	0	0.00	0.00	132.50

Übungsserie 6

Terminmanagement & Kapazitätsmanagement

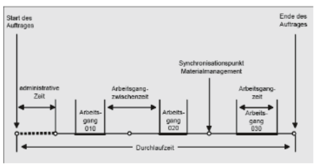
Buffer and Queues



We observe:

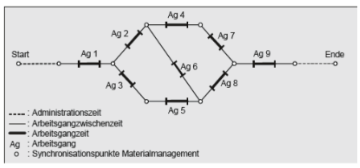
Capacity utilization $\rho = \lambda/\mu$ Vs. Lots in system N_S / Waiting time in system t_S

Lead Time



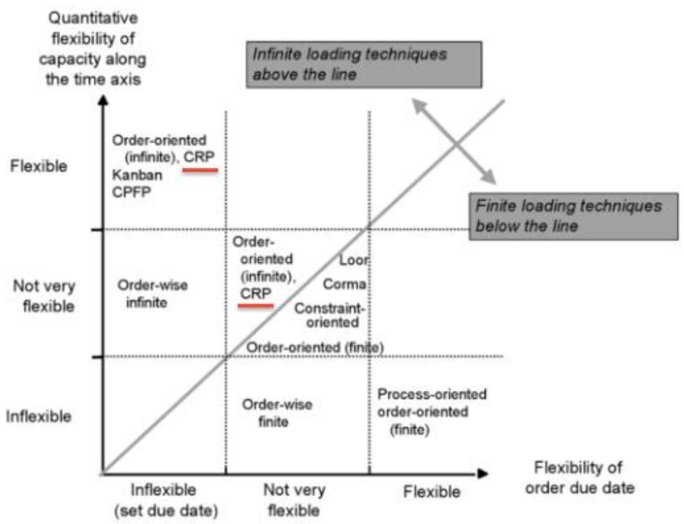
Case: A sequence of operations

In a sequence of operations case, the lead time is equal to the sum of all operations times, interoperation times, and administrative times



A net work of operations

In a directed network of operations, the lead time corresponds to the longest path through the network.

<table>
<tr><td>Infinite Loading</td><td></td><td>


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Übungsserie 8

Kanban with JIT

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<tr><td>Kanban-Cards</td><td>Anzahl Kanban-Karten</td><td>

$$A \cdot k = VDLZ \cdot (1+SF) + w \cdot k$$

$$= \frac{VP \cdot DLZ}{TP} \cdot (1+SF) + w \cdot k$$

$$= \frac{VP \cdot (w \cdot k \cdot SUMEZ + SUMRZ + SUMZWI)}{TP} \cdot (1+SF) + w \cdot k$$

A:	Anzahl Kanban-Karten
k:	Anzahl der Teile pro Behälter
DLZ:	Produktons- bzw. Beschaffungsdurchlaufzeit
VDLZ:	Verbrauch während der Durchlaufzeit
TP:	Länge der Statistikperiode
VP:	Verbrauch während der Statistikperiode (= Erwartungswert des Bedarfs)
SF:	Sicherheitsfaktor-%Satz (für Bedarfsschwankungen und Lieferverzögerungen)
w:	Anzahl der Behälter pro Transportlos (=1, wenn möglich)
SUMEZ:	Summe der Einzelzeiten
SUMRZ:	Summe der Rüstzeiten (losgrössenunabhängig)
SUMZWI:	Summe der Arbeitsgangzwischenzeiten plus Administrationszeit

</td></tr>
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Übungsserie 9

Value Stream Mapping & OEE

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<tr><td>OEE
(Overall Equipment Effectiveness)</td><td>Gesamtanlageneffektivität</td><td>

OEE = Availability * Performance * Quality

Availability rate = Operation time / Planned production time
Performance rate = (Ideal cycle time * total pieces) / Operation time
Quality rate = good pieces / total pieces

➔ results all in %

Planned Production Time = [Shift Length - Breaks]
Operating Time = [Planned Production Time - Down Time]
Good Pieces = [Total Pieces - Reject Pieces]

OEE = (Good Pieces x Ideal Cycle Time) / Planned Production Time

</td></tr>
</table>

		= Fully Productive Time / Planned Production Time OEE (II) = Good units / Theoretical output
Übungsserie 11 Six Sigma & SPC		
p-chart		$Centrale\ line\ (\bar{p}) = \frac{Number\ of\ defects\ in\ sample}{Sample\ size}$ n = single sample size