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# A TRADING SYSTEM FOR FLEXIBLE VWAP EXECUTIONS AS A DESIGN ARTIFACT

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# A TRADING SYSTEM FOR FLEXIBLE VWAP EXECUTIONS AS A DESIGN ARTIFACT

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## Abstract

*Volume Weighted Average Price (VWAP) is widely used by institutional investors as benchmark for the execution of large equity orders. To meet the benchmark, investors have the possibility to either cross their orders in a non-intermediated electronic system or to submit a VWAP agency order to a broker. A design artifact addressing and solving the flexibility restrictions present in today's VWAP crossing is the flexible VWAP crossing model. This work extends the model presenting the rescaling and carrying functions and demonstrating a prototype trading system utilizing the model. Pilot runs show the crossing ratio of the system using random data.*

Keywords: VWAP, securities trading, trading system, design research

# 1 INTRODUCTION

The size of institutional investors' (e.g. hedge funds, mutual funds) orders to buy or sell securities can range up to several percent of the average daily traded volume. Trading such orders on today's electronic trading venues (venue is used as a broad term for exchanges, multilateral trading facilities and other services for order execution) is subject to trading risk and the associated explicit as well as implicit transaction costs of trading, e.g. opportunity costs and market impact (Schwartz and Francioni 2004, Massim and Phelps 1994), which can be high (Bikker et al. 2007) for the particular type of investors.

A factor influencing the costs is liquidity. Liquidity can be defined as the ability to trade whenever one wants to trade (Schwartz and Francioni 2004). When liquidity is fragmented, the demand or supply of securities and the corresponding cash are split over multiple trading venues and thus, the ability to trade is limited.

One way to manage (Bertsimas and Lo 1998) and minimize these costs is trying to execute these orders at an average price like the volume weighted average price (VWAP, the ratio of the value traded to total quantity traded over a particular time horizon). The VWAP is easy to measure, easy to communicate and is provided by most information vendors (Schwartz and Francioni 2004). It can also be used as a reference price for execution comparisons.

Investors have mainly two options to execute an order at the VWAP: using a VWAP crossing system (Ramistella 2006) or submitting an agency VWAP order to a broker.

A crossing system is a "satellite trading place; it uses prices derived from some primary market, and merely matches on quantity" (Naes and Odegaard 2005, p. 1). Investors submit desired buy and sell quantities (their demand or supply), which are then matched at a prearranged price. In full day VWAP crossing, the quantities are matched before the start of trading on the reference venue (reference venue is a chosen venue, from which prices are derived), which is also the start of VWAP calculation. The VWAP is determined after trading on the reference venue ends and both the value and quantity traded over the day are known.

The existing trading model of full day VWAP crossing separates price and quantity negotiations from each other, such that the size of the order has no market impact. The strategy of trying to cross big orders in the first place before trading them in chunks over time has been shown to be cost effective (Naes and Skjeltorp 2003). However, crossing is subject to price movement and high opportunity risk. The performance of a crossing system is measured by the crossing ratio, the executed (crossed) quantity as proportion of the submitted quantity. State of the art crossing systems have rather low crossing ratios (Naes and Odegaard 2005).

Although the agency VWAP is subject to transaction costs and broker trading behavior is not without critique (Edelen and Kadlec 2006), it is used as an alternative to crossing because it offers flexibility to the investor. First, the investor can specify a time period other than the whole trading day, for example the VWAP for several hours. Additionally, the order can be cancelled during execution, e.g. if important news regarding the traded instrument occur. Finally, the investor has the chance that his order is executed at a price better than the VWAP.

Thus, we have two trading venues for execution of VWAP orders fragmenting the liquidity, as e.g. the demand communicated to the broker is unavailable within a crossing system.

Given that the flexibility advantages of the agency VWAP and the low costs in VWAP crossing systems are attractive to institutional investors, a new trading model has to include at least some comparable value proposition. Thus, the goal is to develop a hybrid model offering the combined benefits from existing models. Such a model could also aggregate the liquidity currently fragmented across both execution options.

Utilizing the design science approach (Hevner 2004), the flexible VWAP crossing model has been developed as an artifact offering flexibility regarding the time dimension, as it allows the specification of VWAP periods other than full day and presents a form between crossing and VWAP algorithms.

Besides the base model, the implementations of two relaxation functions, “rescaling” and “carrying”, improving the crossing ratio as quality measure, is presented. The carrying function is addressing the “near match” side issue named by Hasbrouck, where no trade occurs on an electronic venue because the parameters of buyer and seller orders are not exactly equal.

Artifact instantiation proving the feasibility of the model is demonstrated by a prototype trading system utilizing the model. As initial experimental evaluation, pilot runs show the performance of the system using artificial random data.

The remains of this work are structured as follows: section 2 provides an overview of existing work. Section 3 presents the artifact of flexible VWAP model as well as its extensions. Section 4 describes the prototype system while section 5 shows the results of pilot runs. Finally, section 6 concludes.

## **2 RELATED WORKS**

According to Roth (2002), “economists have lately been called upon not only to analyze markets, but to design them. Market design involves a responsibility for detail, a need to deal with all of a market’s complications, not just its principle features”. A market can be seen as an artifact (Subrahmanian & Talukdar 2004), and market engineering has been developed as a structured approach dealing with both technical and economic objectives (Weinhardt et al. 2003). Information systems research contributes to the development of electronic markets providing better economic outcomes (Anandalingam 2005). From the information system perspective, design science (March and Smith 1995, Hevner et al. 2004) offers a suitable approach for design of electronic venues.

In the academic literature, work on VWAP trading or crossing in general focuses on the investor’s perspective, an extensive overview on the topic is given e.g. by Madhavan (2002). Research has been done for optimizing of VWAP trading strategies providing a more detailed insight into agency VWAP execution. The optimal execution strategy is calculated by an iteration of a single variable optimization (Konishi 2002) or utilizing a dynamic, adaptive approach (Bialkowski 2008). Another algorithm for agency VWAP trading, evaluated on a simulation market has been developed by Kakade et al. (2004). Overall, the design and optimization of agency VWAP strategies lead to improved results, but there is still a price deviation from the theoretical VWAP.

Agency trading is also subject to an execution error, particularly regarding the time dimension (Lamoureux and Lastrapes 1990, Lee and Rui 2002). Optimal execution times lag behind expected market trading volume distribution, adding to the risk to miss the desired VWAP.

As stated by Edelen and Kadlec (2006), the evaluation of a trader’s performance (the intermediaries offering agency VWAP) by portfolio managers is mainly based on a comparison of the price per share that the trader has reached and the VWAP during a whole trading day. It is empirically shown that this fact fortifies the principal-agent problem. This is a drawback of agency VWAP and motivates the development of an IT artifact without human traders.

In contrary, crossing offers the exact VWAP because, seen as a negotiation mechanism, the investors agree upon trading at exactly this price. The benefits of crossing are addressed by Almgren and Lorenz (2006) as well as Naes and Skjeltorp (2003), who show that the strategy of trying to cross big orders in the first place before utilizing other venues has been shown to be cost effective. However, by means of one institutional investor’s data set Naes and Odegaard (2005) provide evidence that the low effective trading costs for crossing networks are offset by the costs of non-trading. The low crossing ratio leaves unexecuted quantity (either supply or demand), whose compensatory acquisition is costly.

Degryse et al. (2004) develop a model with competition between a dealer market and a crossing network. Utilizing the model (Degryse et al. 2006), they found an order creation effect leading to

order submissions to the crossing network which would never occur at the dealer market. Within their model evaluation, they alter the opaqueness parameter of the crossing network, representing the rare literature contribution to the design of new mechanisms for automated trading from a design science or market engineering perspective.

The design of mechanisms for VWAP trading, i.e. the derivation of market models, market design and automated trading venue to satisfy investors' needs, can't be found in literature yet, although trading venue is one of the important determinants of price effects of trades (Bikker et al. 2007).

From IS perspective, the contributions of this work are the development of a new model and automated venue as an artefact following the design science approach and the automation of agency VWAP trading. From economic perspective, the model contributes by the integration of two trading venues into a single hybrid one, consolidating liquidity and having an expected additive value for institutional investors.

### 3 FLEXIBLE VWAP TRADING MODEL

#### 3.1 Basic trading model

This section briefly presents the design artefact, the flexible VWAP crossing model initially developed by Gomber et al. (2007), which shares some characteristics of a crossing system. The crossing auctions are performed before the VWAP calculation starts (forward crossing). The order book, which is the data structure holding all buy and sell orders, is partially closed, that is only information about trading interest and time of this trading interest are displayed while information about volume is kept hidden. As in other crossing systems, the market impact is assumed zero and the focus is on reduction of opportunity costs resulting from unexecuted quantity, which means rising of the crossing ratio measure. An additional goal of the system is to allow the investor to achieve a transaction price as close to his desired VWAP as possible.

The key idea of the flexible VWAP model is that crossing auctions are triggered based on the start times of the VWAP intervals submitted as order parameters by investors rather than being fixed and specified by the provider of the execution venue. As utility, this provides full flexibility concerning the time intervals in which the VWAP is determined and thereby differs substantially from existing VWAP crossings. This flexibility can be found when using agency VWAP, making the flexible VWAP a model between crossing and agency VWAP. Due to automation and implementation, the service can be offered at low costs as in a crossing network.

Symbol	VWAP Start	VWAP End	Open	Close	High	Low
DE0007100000	10:00	10:30	69.00	68.42	69.12	67.81
	10:00	11:00	69.00	68.42	69.12	67.81
	10:00	12:00	69.00	68.42	69.12	67.81
	11:00	12:00	69.00	68.42	69.12	67.81
DE0008404005	13:00	15:00	69.00	68.42	69.12	67.81
	10:00	11:30	140.33	139.26	141.94	138.25
	10:15	11:45				

Figure 1: Order book snapshot at the front-end.

First of all, a basic order submitted to the system has the parameters security identifier, quantity, buy/sell indication, VWAP calculation start time and VWAP calculation end time (the times specify an interval for the calculation).

Besides the desired start and end times, the order book is closed in a way that neither volume nor market side information is shown in order to prevent influence on the reference venue. Volume and willingness to buy or sell are information which can influence the price formation on the reference venue. As a consequence, the displayed order book (see figure 1 showing orders with five different VWAP calculation periods (e.g. 10:00 - 10:30) for the first instrument, enriched by reference market information: today's opening, high, low and yesterday's closing prices) presented in an investor's front-end is concentrated on the VWAP calculation periods of orders in the book. Trading is anonymous, so investors do not know each other in advance of the trade.

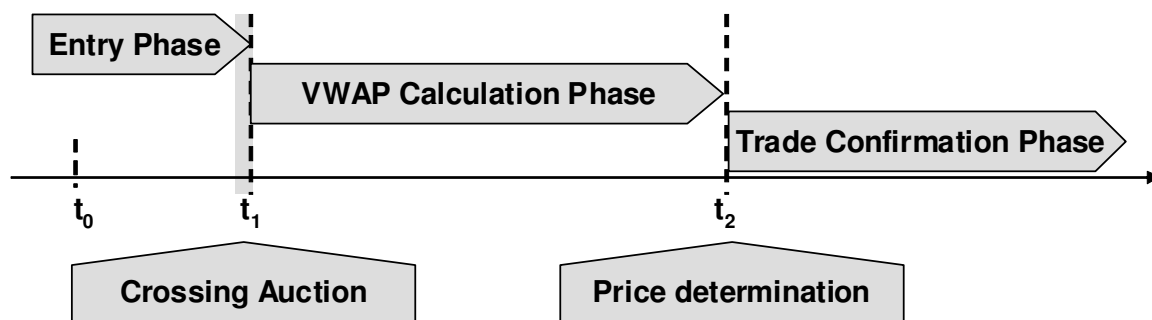


Figure 2: Trading phases of the system

The distinct phases of transaction are order entry phase, crossing auction, VWAP calculation phase, price determination and confirmation (see figure 2).

There is no fixed order entry phase. Since an order with a new start time parameter can arrive any time, the next auction time is not known in advance. The first order with a new start time  $t_1$ , arriving at  $t_0$ , dynamically defines an entry phase for the particular auction. Other investors can join the auction by submitting orders with identical start and end times, as the public displayed order book shows these times. All orders willing to interact with the first one or with the same start time ( $t_1$ ) must be entered before this start time in order to participate within the crossing auction at  $t_1$ . Additionally, orders can be cancelled before the start of the crossing auction. The order entry time is important for the time priority as one factor for the matching mechanism.

Shortly before (such that the auction results are available at start time, i.e. 1 min) the start time  $t_1$ , the crossing auction is triggered, matching orders based on the matching rules, that is all orders with exactly matching time intervals - i.e.  $t_1$  (start time) and  $t_2$  (end time, see figure 4) are identical - are matched (e.g. buy and sell orders for a two hours interval 10:00 – 12:00 are matched against each other, as well as orders for different intervals like 10:00 – 11:00). Thus, the crossing auctions are triggered by the start time parameter of orders. To this point, the crossing is comparable to existing full day VWAP crossing systems except for the flexible time interval. Orders are matched based on time priority of order entry to reward users which have revealed their preferred time period to the market. As the VWAP is imported from a reference market and set as the transaction price for all executed orders, there exists no price priority by design.

Orders cannot be withdrawn anymore as soon as the auction starts. After the crossing, execution confirmations with the executed quantity are sent to investors. The execution confirmations have no counterparty information to prevent a black board effect where investors could submit only a small quantity to the crossing system and negotiate their real quantity bilaterally with counterparties disseminated through the confirmations. These investors already have shown their acceptance of the time period and would be potential counterparties for bigger trades, which could lead to lower liquidity in the actual system.

At the time the auction ends, the calculation phase for the corresponding VWAP begins. The VWAP for the specified period will represent the price for the trades already crossed in the auction.

Additionally, after the crossing auctions end, at the beginning of the VWAP calculation, unexecuted quantity is handled.

At  $t_2$ , the calculation of the VWAP ends and the price of the transactions is determined by importing the VWAP from a reference venue or information provider. This price allows for enrichment of the trade data completing the transaction.

After  $t_2$ , the trade confirmations are prepared and sent to the investors, including all data required for post trade processing. This includes data previously included in the execution confirmations as well as price and counterparty information. Together with confirmation of the trades, reports required by regulation are prepared and sent and the transaction information is disseminated to the market.

Since investors are free to specify the time periods, these trading phases are present for every single period. This includes overlapping ones, which are relevant within the matching mechanism.

The time flexibility introduced in the basic model reduces the crossing ratio and the “near match” problem occurs, as orders can have incompatible parameters. Two functions, “rescaling” and “carrying”, extend and refine the basic model, compensate for this combinatorial effect and allow an extension of the matching rules.

### 3.2 Rescaling and Carrying functions within the trading model

Rescaling allows crossing of orders for varying intervals with same start time, for example an order for a 10:00 – 12:00 interval can partially interact with an order for a 10:00 – 11:00 interval (see figure 3). The mechanism rescales the order quantity based on a linear volume pattern. As Hobson (2006) states that e.g. innovations in the volume profile of VWAP strategies yield an “insignificant benefit”, the linear volume pattern represents a minor simplification of the real world.

After this quantity adjustment, the rescaled order can interact with another one for the shorter interval. The remaining quantity enables the investor to still achieve his desired VWAP. As the VWAP for a shorter period (e.g. two hours) will typically differ from the VWAP for a longer period (e.g. four hours), the quantity will be held back to be executed in the delta of the intervals, in the above example between 11:00 and 12:00. Investors can influence whether his order will be rescaled by execution instructions as additional order parameters. The “strict” instruction disables rescaling while “rescale” enables the application of the function on a particular order.

This function leads to an extension of the basic matching rules such that, after the first auction, unexecuted orders are rescaled and the auction mechanism is applied on the remaining and rescaled orders.

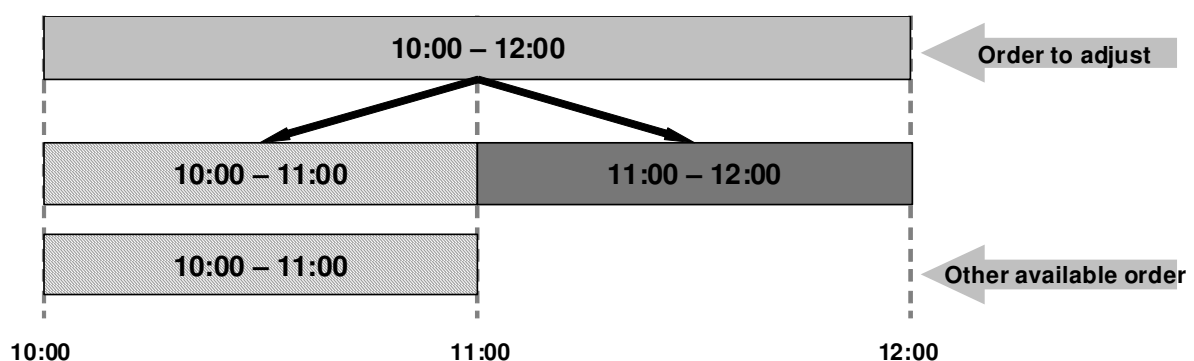


Figure 3: Rescaling of an order for a 10:00 – 12:00 interval to a shorter 10:00 – 11:00 interval.

The second function, “carrying”, handles unexecuted quantity after auctions for a particular start time (see figure 4). The function aims at keeping liquidity in terms of unexecuted quantity within the

system by tweaking the order parameters. The near match problem is addressed, as carried orders are transformed by this function and matching is enabled. A first possibility is to forward the start time of the order while keeping the end time fixed (1), effectively shortening the interval, e.g. transforming a 10:00 – 12:00 order into a 10:15 – 12:00 order. Depending on investor’s choice communicated through handling instructions as another order parameter, the quantity can be kept fix (good till time instruction) or become rescaled (carry forward end fix instruction). A second possibility is to keep the interval fixed changing both the start and the end time simultaneously (2). In this case, quantity needs not to be adjusted, e.g. carrying the 10:00 – 12:00 order forward to 10:30 – 12:30. Finally (3), one handling instruction cares of the remainder from the rescaling function. This can be seen as a special case of the first possibility where time  $t$  is known in advance.

The carrying function selects the appropriate orders from the order book and carries them forward whenever a new, later, auction time  $t$  is reached. Thus, it is called right before an auction.

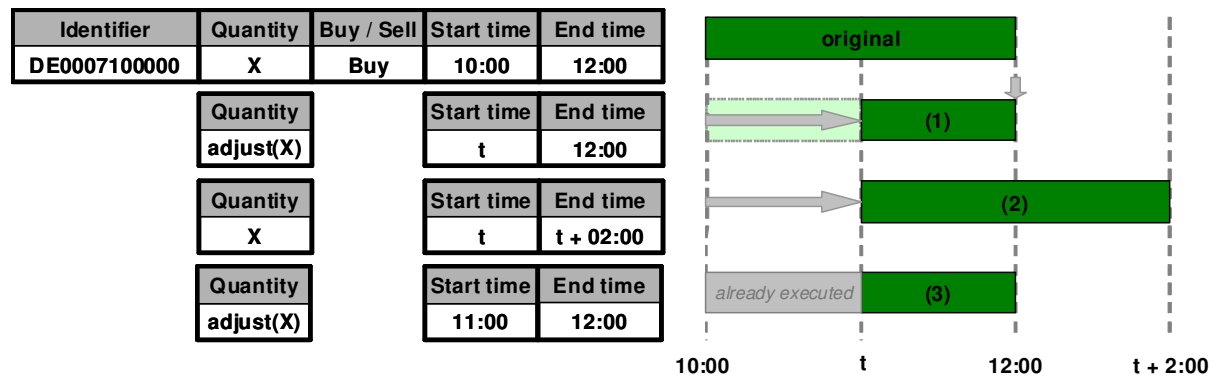


Figure 4: Examples of the carrying alternatives

The combination of execution and handling instructions leads to system specific order types. Inappropriate combinations (e.g. denying rescaling as execution instruction while allowing it by handling instruction) lead to a reduced number of possible order types.

The model is completed by a visibility concept such that only the start and end times are publicly displayed and by safeguards against exceptional market conditions enabling trade cancelations.

#### 4 PROTOTYPE IMPLEMENTATION OF THE MODEL

As a proof of concept and preparation for future experiments and simulation studies, an initial prototype of the system has been implemented using the Java programming language. The prototype as instance demonstrates feasibility as a proof by construction (Nunamaker 1991) and initial evaluation step. The prototype consists of an order book, a time manager, an auction engine as well as a rescaling and a carrying module (see figure 5). A graphical interface (see figure 6) has been added, displaying the content of the order book and allowing manual control of the system.

The Order book is the main data storage entity for orders. As a design choice, datasets are persistent, e.g. orders are not deleted but only marked as such using the corresponding order status. As real orders would represent monetary value, keeping this information follows common practical design. The possible states of orders, state changes as well as attributes have been adapted from the Fixprotocol specification version 5.0 (FIX Protocol Ltd. 2008). FIX is an industry standard



communication protocol defining various message types and state transitions during an order life cycle.

The core data entity is order. Orders are kept within the order book, which can be represented by a database or other suitable structure with basic operations like insertion of a new order, deletion, update or selection of an order set. Any application of auction, rescaling or carrying function results in manipulation of order data.

To reflect the dynamic setting of auction times, changes to the order book (e.g. new order insertions) result in notifications being published to subscribers like time manager. The observer (publish – subscribe) design pattern has been utilized both for order and order book, allowing updates to graphical interfaces or notifying remote users through communication interfaces.

Information like validity of a security identifier (reference data) is imported as exogenous market information.

The Time Manager (TM) carries about the time progress of the system. It is notified about changes to the order book and stores the next point in time when an event or action sequence has to be triggered (event time), e.g. the nearest auction time or next expiry time. Whenever an order has a start time parameter which is before the next “event time” and is still in the future, this value is updated. Once this time is reached, time manager triggers the necessary tasks, e.g. an auction, an order book update or sending of final trade notifications after a calculation end time has been reached. All times except the static start and end of trading can be extracted from the order book, as they are defined by order parameters. The Time Manager has the control over the system process, being aware of function and task sequences, e.g. carry orders, perform auction and handle remaining quantity.

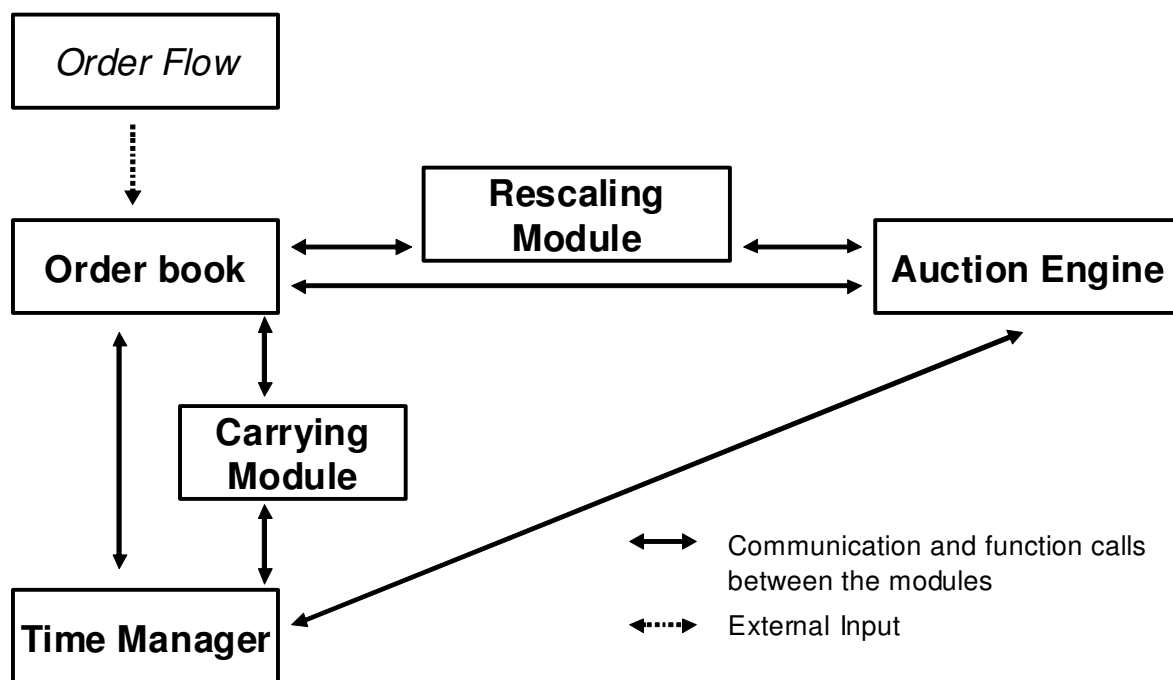


Figure 5: Base setup of the model

The Auction Engine provides the functions to match orders against each other. Once activated, the orders with the appropriate parameters given by the time manager are selected from the order book.

Since a VWAP crossing auction needs no internal price determination and orders can be partially filled, matching of corresponding orders is a straightforward function where orders are separated in

buy and sell orders, ordered according to the priority rules (entry time) and the sorted orders are matched one by one sequentially (whereas partial executions occur internally) until there are no orders left on one side (buy or sell) or other constraints are met. Matching priority rules can be altered by changes to the sorting of orders.

The Rescaling Module provides the logic to adjust the quantity of orders. Rescaling has been implemented by replacing the original order (e.g. for a 10:00 – 12:00 interval) with two others having the corresponding interval and quantity fractions as parameters (e.g. one from 10:00 – 11:00 and another from 11:00 – 12:00, see figure 6). This has been adapted from modification mechanisms on existing trading venues, where a modification (replace) is internally a combination of a cancellation and a new entry. Only suitable orders (with appropriate instructions and status) are rescaled according to their time priority, eldest orders being rescaled first. By determining the available quantity on the opposite side in the targeted interval (e.g. 10:00 – 11:00), rescaling multiple orders can be aborted when this quantity has been reached. Additionally, a rescaled order can be further split up for even shorter intervals. During an auction, the matching mechanisms followed by rescaling are applied iterative starting with the longest interval.

Symbol	ID	Quantity	Open	Executed	Side	VWAP Start	VWAP End	Ordertype	Entry Time	Status
DE0007100000	1	40000	20000	20000	Buy	2008-08-21 10:00:00	2008-08-21 11:00:00	RESCALABLE KEEP_REMAINDER	2008-07-24 15:31:57	Partially Filled
DE0007100000	2	20000	0	20000	Sell	2008-08-21 10:00:00	2008-08-21 11:00:00	RESCALABLE KEEP_REMAINDER	2008-07-24 15:31:57	Filled
DE0007100000	3	30000	0	30000	Buy	2008-08-21 10:00:00	2008-08-21 12:00:00	RESCALABLE KEEP_REMAINDER	2008-07-24 15:31:57	Filled
DE0007100000	4	40000	0	40000	Buy	2008-08-21 10:00:00	2008-08-21 12:00:00	RESCALABLE KEEP_REMAINDER	2008-07-24 15:31:57	Filled
DE0007100000	5	40000	0	40000	Sell	2008-08-21 10:00:00	2008-08-21 12:00:00	RESCALABLE KEEP_REMAINDER	2008-07-24 15:31:57	Filled
DE0007100000	6	50000	0	50000	Sell	2008-08-21 10:00:00	2008-08-21 12:00:00	RESCALABLE KEEP_REMAINDER	2008-07-24 15:31:57	Filled
DE0007100000	7	20000	0	20000	Buy	2008-08-21 10:00:00	2008-08-21 12:00:00	RESCALABLE KEEP_REMAINDER	2008-07-24 15:31:58	Filled
DE0007100000	8	20000	0	20000	Sell	2008-08-21 10:00:00	2008-08-21 12:00:00	RESCALABLE KEEP_REMAINDER	2008-07-24 15:31:58	Filled
DE0007100000	9	20000	20000	0	Sell	2008-08-21 10:00:00	2008-08-21 12:00:00	RESCALABLE KEEP_REMAINDER	2008-07-24 15:31:58	Replaced
DE0007100000	10	20000	0	20000	Buy	2008-08-21 10:00:00	2008-08-21 12:00:00	RESCALABLE KEEP_REMAINDER	2008-07-24 15:31:58	Filled
DE0007100000	11	20000	20000	0	Sell	2008-08-21 10:00:00	2008-08-21 12:00:00	STRICT_FIXED_AUCTION	2008-07-24 15:31:58	New
DE0007100000	13 / 9	10000	10000	0	Sell	2008-08-21 10:00:00	2008-08-21 11:00:00	RESCALABLE KEEP_REMAINDER	2008-07-24 15:31:58	New
DE0007100000	14 / 9	10000	10000	0	Sell	2008-08-21 11:00:00	2008-08-21 12:00:00	RESCALABLE KEEP_REMAINDER	2008-07-24 15:31:58	New

Figure 6: Prototype view during auctions at 10:00. Order with ID 9 has been rescaled leading to two new orders 13 and 14 (the ID of the originating order 9 after the new IDs is displayed for tracking purposes)

Carrying has been set up as a two stage task performed by the carrying module which is activated by the time manager. Before an auction task is triggered, pre-auction handling (first stage), where the start time of eligible orders is temporary fixed for the auction, is performed. Depending on handling instructions, quantity is rescaled utilizing the logic of the rescale function (different method within adjustment module). After carrying, a selection of orders for the auction (from the order book) will include the carried ones. After the auctions, post-auction handling (second stage) deals primarily with partially or unexecuted eligible orders whose previously fixed start time will be reset on their dynamic “wildcard” value.

## 5 RESULTS OF SYSTEM PILOT RUNS

Pilot runs of the system as one of the initial steps for a simulation study (Law and Kelton 2000) as well as experimental artefact evaluation (Hevner 2004) have been performed.

The first setup consists of a single auction time (10:00) in one instrument with 100 random generated orders. All orders have the same VWAP calculation start time (10:00), but intervals of different length, where end of trading has been set to 18:00. Time granularity has been set to a multiple of half

an hour reducing the universe of possible intervals (e.g. 10:00 – 10:30, 10:00 – 11:00 ...). The parameter  $p_r$  is the probability to generate a rescalable order. The probability to generate a buy order is  $p_{bs}$ , such that on average, up to  $p_{bs}$  will be buy orders and  $1-p_{bs}$  will be sell orders. For every parameter combination tested, 500 auctions were run, where the random seed was changed every 100 auctions.

As a measure of utility, the delta of crossing ratio after and before rescaling is used. As crossing ratio, the crossed quantity (buy and sell) representing trading is compared to the total quantity (on both sides) representing trading wishes in the book. Taking the whole quantity as denominator makes a crossing ratio value of one unlikely, as there is typically a surplus of buy or sell quantity.

The delta of crossing ratio decreases when the probability to generate a rescalable order is lowered while  $p_{bs}$  has been fixed to 0,5 (see table 1). With 10% of rescalable orders ( $p_r = 0,1$ ), the positive delta (improvement) is 4,3 % on average, rising to 18,9 % on average with rescalable orders only ( $p_r = 1,0$ ).

Additionally,  $p_{bs}$  has been altered while  $p_r$  was set to 0,5. With only 20 % buy orders ( $p_{bs} = 0,2$ ), the improvement was 4,3 % on average, doubling to 8 % with  $p_{bs} = 0,3$  (see table 1).

$p_r$	Delta CR, $p_{bs} = 0,5$	$p_{bs}$	Delta CR, $p_r = 0,5$
1,00	0,189	0,5	0,134
0,50	0,134	0,4	0,126
0,25	0,084	0,3	0,080
0,10	0,043 (0,04277)	0,2	0,043 (0,04274)

Table 1: Delta of crossing ratio with different probabilities for a rescalable order and a buy order

The evaluation of pilot runs with random data shows that rescaling is able to raise the crossing ratio, even under unusual conditions like only few rescalable orders. Even an extreme parameter combination ( $p_r = 0,1$  and  $p_{bs} = 0,1$ ) lead to an average delta of crossing ratio improvement of 1,3 %.

A second setup consists of multiple auction times covering a trading day. The probability to generate a buy order,  $p_{bs}$ , is 0,5. The comparison of a trading day utilizing both rescaling and carrying functions (with  $p_r = 0,5$  equally distributed among the corresponding handling instructions) with a trading day utilizing only strict, fixed auction time orders (no rescaling and no carrying) results in an improvement of 10,4 % on average. The comparison with a setup allowing orders which can be carried forward without rescaling (good till time and carry forward period fix orders) also shows a delta CR of 1,8 %.

The pilot runs show that the simulation artefact offers a good crossing ratio while enabling the time flexibility of agency trading. Further, the “near match” problem resulting from the added flexibility is addressed such that although orders can’t be matched in first place, rescaling and carrying lead to additional matches for orders whose parameters are close to each other.

It should be mentioned as a limitation that because institutional investors are assumed informed investors, their orders and order submissions follow external rules and thus, random orders (e.g. input from minimal intelligence agents (Cliff 1997)) might be an insufficient proxy.

## 6 CONCLUSIONS

From a market microstructure perspective, a branch of economic research concerned with the details of how exchange of transaction objects occurs on markets, O’Hara (1999) states that “we are, perhaps, in the perplexing situation that while markets appear to work in practice, we are not sure they work in

theory”. Design science and market engineering enable researchers to design and evaluate trading venues in theory and take a formative rather than observing role.

In order to have their orders executed at the VWAP, investors can submit a VWAP agency order to a broker or make use of a fully electronic crossing facility. Existing VWAP crossing facilities are characterized by some inflexibility while agency VWAP is subject to execution risks. This work develops and presents a unique trading venue artifact, a model with flexible VWAP sessions (residing between full day crossing and agency VWAP) concerning start time, end time and time period. Recent developments within the trading landscape regarding hybrid venues, where venue operators (see e.g. Liquidnet’s model at [www.liquidnet.com](http://www.liquidnet.com)) are trying to integrate so called “dark pools” with their supply and demand into their venues to improve liquidity and market outcomes underpin the interest of institutional investors into new trading venues.

The developed and implemented trading system addresses the inflexibility. The implementation of the two functions, “rescaling” and “carrying” and pilot runs of the prototype implementation demonstrate the feasibility of the model and show results regarding the crossing ratio achieved within the system.

The next research step is a full simulation study as well as a lab experiment. Following the approach of Degryse et al. (2006), the venue will be evaluated in a competitive environment to evaluate if and under which conditions investors are willing to utilize the new venue. Especially the results of the lab experiment are expected to show an ‘intention to use’ based on a ‘perceived usefulness’ indicating the expected utility of the venue.

Discussions with both infrastructure providers and investors will assess the detailed needs and requirements of investors regarding such system and help to determine parameters (e.g. handling instructions) with the highest acceptance.

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